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AN INVESTIGATION OF SECONDARY JETTING PHENOMENA "HYPERJET" SHAPED CHARGE

August 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Secondary jetting phenomena, the formation of high velocity jets from the collision of several primary (normally formed) shaped charge jets,was experimentally demonstrated during this program. A one dimensional computer simulation code "HYJETS" was also developed to evaluate various design concepts by simulating jet formation performance.

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SECTION A

INTRODUCTION

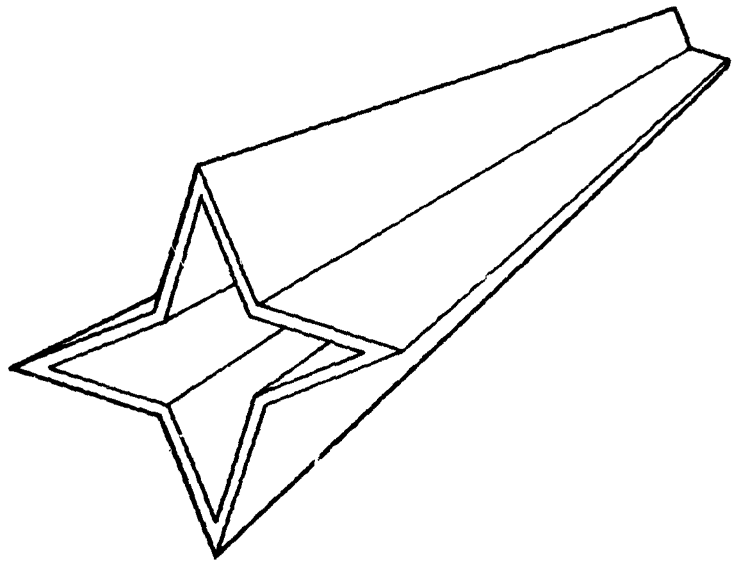
A. INTRODUCTION

1) General This contract was issued as a feasability effort to demonstrate practical applications of Hyperjets, a novel shaped charge concept. A computer simulation program was generated and identified as " HYJETS" to model and analyse several baseline designs; each design represented a hyperjet condition. Based upon this simulation work, several prototype shaped-charge designs were manufactured and tested, the results of which are contained in the following sections of this report.

2) Background Results of a previous LSI in-house effort identified a family of shaped-charge designs which would (theoretically) amplify typical shaped-charge jet velocities by an order of magnitude. Each of these designs employs a jetting effect referred to as a "secondary jetting phenomenon" (the collision of several primary sheet jets, resulting in further secondary jets having significantly higher velocities). The basic design chosen to demonstrate this concept is a tapered , star-cone liner (see Figure 1) which is a symmetric arrangement of four wedge shaped arms, each in intimate contact with an explosive charge. Each component upon explosive initiation forms a primary sheet jet; the four sheet jets so formed collide along a common axis, resulting in a secondary jet, the nature of which is the subject of this contractual effort.

3) Scope of Work In April, 1980, Contract# DAAK10-80-C-0078 was issued to LSI by ARRADCOM to conduct a feasability study demonstrating the secondary jetting phenomenon and its effects. This was to be accomplished in a three phased effort.

TASK 1-Design Phase This phase requires the development of a one-dimensional computer code capable of being used in



STAR CONE (4) POINT

Figure 1. Star Cone Configuration Exemplifying Secondary Jetting

the design of Hyperjet configurations. This code would be employed to identify and generate several candidate designs based upon the initial LSI concept, which is a symmetric star-cone shape. Each candidate design would include an explosive/initiation system design, integrated with metal components, to produce an optimum terminal effect upon initiation.

<u>TASK 2-Detail and Manufacture</u> This phase involves the selection of a prototype design based upon initial design efforts and modified from the initial designs to meet manufacturing requirements and possible recommendations made by government technical personnel. This prototype design would be fully detailed and a minimum of four metal assemblies manufactured and delivered to ARRADCOM for loading and testing.

<u>TASK 3-Testing and Analysis</u> For this phase, a comprehensive test plan would be prepared, the purpose of which would be to examine jet formation for configurations based upon the Hyperjet design. Primarily flash x ray techniques would be used to measure jet velocities resulting from secondary collisions. A formal report would be prepared; this would report on design, manufacturing and testing results obtained and would analyze those areas where improvements could be accomplished in a follow-on effort.

4) <u>Review of Shaped-Charge Technology and Introduction to Secondary Jetting</u> If one had the goal of increasing shaped-charge jet velocities, one approach would be to increase the liner collapse velocity and thereby achieve a proportionate increase in jet velocity. Conventionally, liner collapse velocities have been increased by increasing the quantity of explosive over the liner, or by decreasing liner thickness. Another not so well known method is that of increasing the

liner collapse velocity by "Focussing" it. That is, if the collapsing liner already is a primary jet (formed from a primary collision), then it could already be traveling at a velocity of from 4 to 8 times as fast as a liner from a "conventional" shaped charge. When this liner-jet in turn collides with other liner jets traveling at the same higher velocity, the resultant jetting collision produces a very high velocity jet, which we refer to as a "secondary" jet.

Before reviewing Secondary-Jetting Phenomena, it is necessary to consider the basic phenomena and configurations involved in conventional shaped-charge technology. Figure 2 illustrates a typical liner/explosive combination. This is a sectional view which would aptly describe either a conical or linear shaped charge configuration. Figure 3 shows a liner, midway through its collapse process, forming a conventional jet and slug. Figure 4 illustrates the flow of liner material into both the jet and slug in the collision region (here, the material flow is shown in stationary coordinates, i.e. with the observer at the collision point and moving along the direction of motion of the collision point). The next two figures (Figures 5 and 6, respectively) illustrate conditions necessary for, and insufficient for, the occurrence of shaped charge jets, It is important to note that, in addition to the requirement that the liner velocity be sufficiently high to effect fluid-like behavior at the collision point, two other requirements are necessary: First, the collapsing liners must meet at a collision point, forming an angular (or curved) shape and second, the liner motion must be in a direction essentially perpendicular to surface of the liner (note that this does not occur in Figure 6).

With this background in mind, it is now appropriate to discuss secondary-jetting phenomena. If two or more shaped-charge jets are directed toward a common point, at least two more

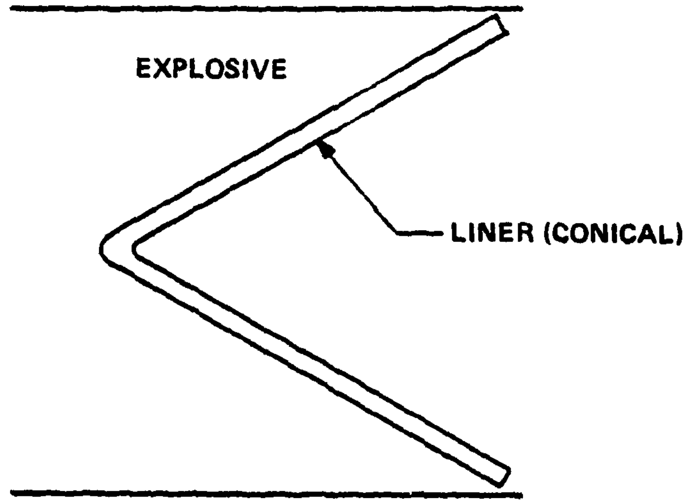


Figure 2 Basic (conventional) Configuration

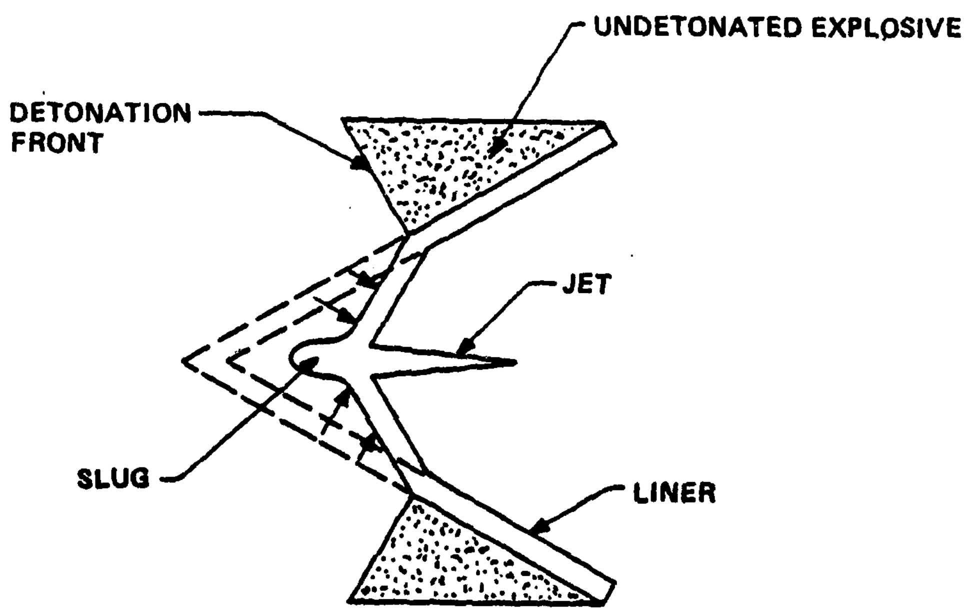


Figure 3 Collapse Process of Conventional Liner

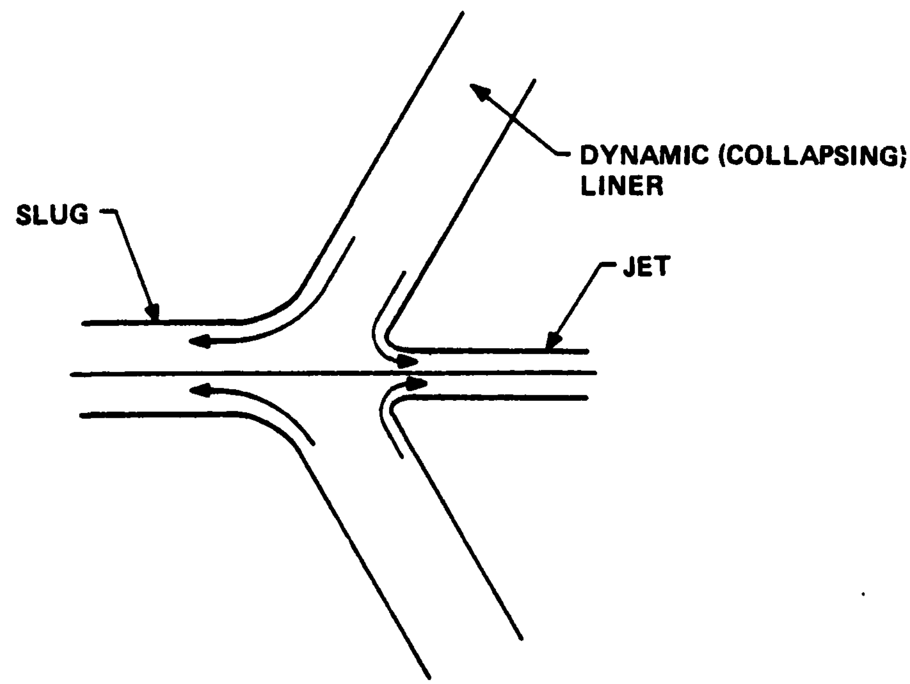


Figure 4 In the Collision Region (material flow in stationary coordiantes)

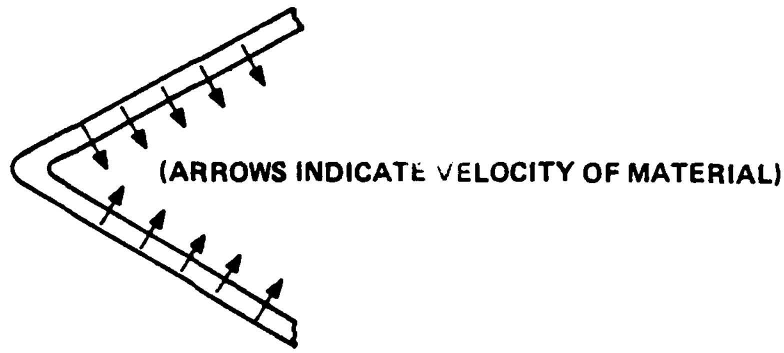


Figure 5 Necessary Dynamic Geometric and Kinetic Condition of the Liners for the Shaped Charge Effect (in real coordinates)

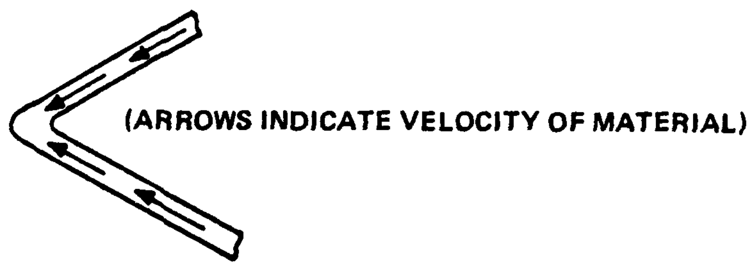


Figure 6 Dynamic Geometric Condition Which Will Not Yield the Shaped Charge Effect

jet streams will result, the size of each outgoing stream varying with the angular configuration of the incoming jet streams. If the incoming jet streams have the same velocity, the outgoing jets will each have that same velocity. In other words, no velocity amplification (or shaped-charge effect) will occur. The configuration and kinetics describing this condition would be that of Figure 6.

LSI has proposed that an arrangement of several opposing pairs of linear shaped charges, configured so that the lines along their apexes form a cone, with the cross sectional areas of each linear shaped-charge section decreasing toward the one central apex of that cone, will upon appropriate initiation, result first in the formation of primary planar-shaped jets (due to the collision of each of the linear shaped charge walls) and then in the formation of Secondary jets (due to the collision of several opposing "planes" of primary jets). The resulting collapse configuration satisfies the necessary and sufficient conditions for yielding a shaped-charge jet, as indicated in Figure 5. A basic liner configuration (called a "star cone) is shown in Figure 1. This configuration was selected for illustrative purposes and mathematical tractability only, since rosette-shaped or hemispherical-shaped liners appear more promising from an overall manufacturing and jet kinetic energy viewpoint.

For the purpose of simplifying the discussion of secondary jetting phenomena, certain nomenclature pertaining to secondary jetting is necessary. Such nomenclature is furnished in the following nomenclature sheet:

Table I. Nomenclature Sheet

- Star Cone - Shaped-charge liner having a star-shaped cross section.

- Primary/Secondary Collisions - Primary collisions of liner material, whereupon primary (shaped charge) jets are formed; secondary collisions are collisions of liner material already having undergone primary collisions, and whereupon further (secondary shaped charge) jets are formed.

- Primary/Secondary Jets - Primary jets are shaped charge jets formed from primary collisions; secondary jets are shaped charge jets formed from collisions of primary jets with each other (secondary collisions).

- Mass Accumualtion - A process by which jet mass, but not necessarily jet velocity, is increased after the collision of jets.

- Velocity Amplification - A process by which jet velocity is increased after the collision of jets.

- Hyperjets/Normal Jets/Hyperjet Slug/slug Jets/Slug-Slugs - A "Hyperjet" is a secondary jet; a "normal" jet is a primary jet; a Hyperjet-slug is the slug formed from the collision of primary jets; a "slug"-jet is a shaped charge jet formed from the subsequent collision of slugs form a primary collision; a "slug-slug" is a slug formed from a subsequent collision of slugs from a primary collision.

- Redirected Jets - Jet collisions wherein the newly formed jet velocity is not increased, but simply undergoes a change in direction and possibly in mass.

SECTION B

DESIGN ANALYSIS

B. DESIGN ANALYSIS

1) Development of the "HYJETS" Code A star cone shaped charge liner consists of a series of wedges arranged symmetrically about a common axis. Its geometry is characterized by four parameters: cone angle ($2\alpha_c$) wedge angle ($2\alpha_w$) liner thickness (h_s) and cone height (L) as illustrated in Figure 7. Upon initiation, as a detonation wave sweeps over the cone, each wedge of the star cone will collapse, froming a sheet jet similar to a linear shaped charge jet. The sheet jets will then collide with each other at the symmetric axis and create a secondary jet.

In order to be able to analytically examine performances of star cone shaped charge configurations, it is necessary to consider what happens when explosively driven wedges, such as the individual arms of the star cone liner, collapse to form a sheet jet. The main explosive charge surrounds the outer shell of the star liner, and is initiated at the symmetric axis some distance,(h_e), in front of the liner apex, (see figure 7). As the detonation wave front sweeps over the wedge liners, high pressure gases cause each plane of a star cone wedge to collapse. Energy considerations can be used to determine the ultimate velocity which each collapsing plane, or liner, can achieve. This is expressed in terms of a Gurney formula (Ref. 1)

$$\frac{V_o}{2E} = \left[\frac{1 + a^3}{3(1+a)} + \phi_c a + \phi_s\right] \qquad \text{Eqns. 1}$$

$$a = \frac{1 + 2\phi_s}{1 + 2\phi_c} \qquad \phi_s = \rho_s h_s/\rho_e h_e$$

$$\phi_c \quad \rho_c h_c/\rho_e h_e$$

Where V_o = Final collapse velocity

E = Gurney energy of explosive

continued

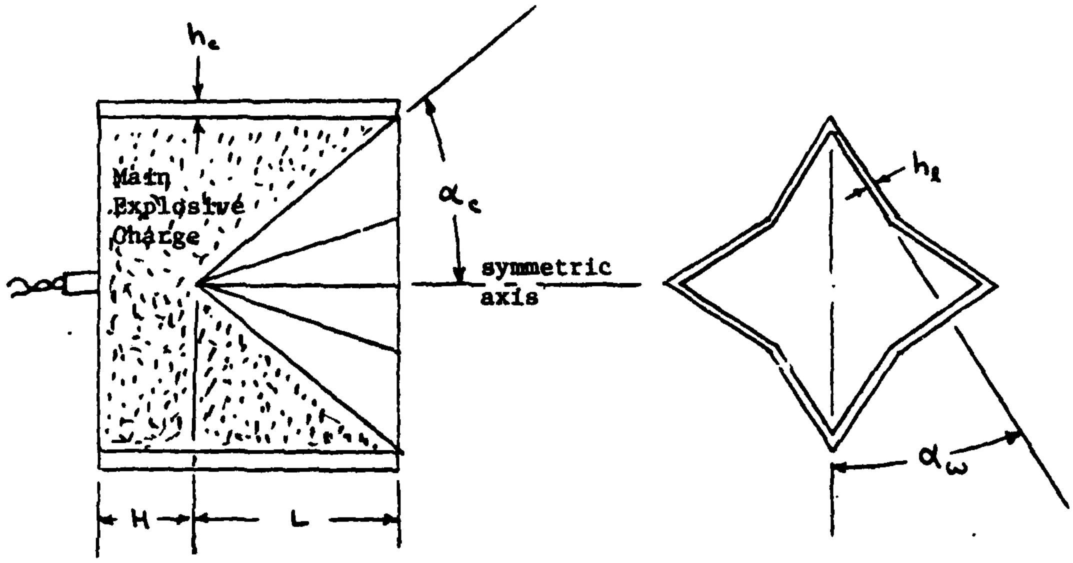


Figure 7. Parameters of Star Cones

ρ_e = Explosive density
ρ_s = Liner density
ρ_c = Confinement density (Casing material)
h_e = Explosive thickness above liner
h_s = Liner thickness
h_c = Explosive confinement (Casing thickness)

If we chose a functional representation of the pressure decay in time, based on known experimental results (Ref.2), we can then reduce the function to an expression for the acceleration of any part of the liner in time:

$$a = \frac{p_{cj}}{\rho_s h_s} e^{-\lambda^2 (t-t_i)^2}$$

$$\lambda = \left[\frac{p_{cj}}{\rho_s h_s}\right] \cdot \left[\frac{\sqrt{\pi}}{2V_o}\right] \qquad \text{Eqns. 2}$$

Where a = Liner acceleration of some point in the liner
p_{cj} = Chapman-Jouget explosive pressure
ρ_s = Liner density
h_s = Liner thickness
t = Time after detonation wave first reaches liner segment
t_i = Time when detonation wave first reaches liner segment
V_o = Final velocity (from Gurney relation) Eqns. 1.

The assumption is made that liner acceleration is normal to the surface of the collapsing liner. Since liner accerleration of any point along the liner is known, it is therefore possible to describe the governing equation of motion as:

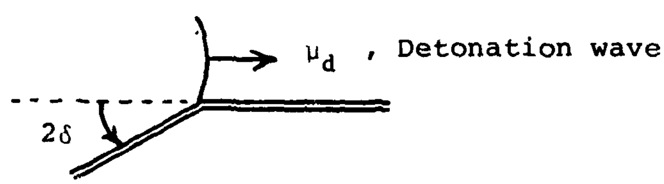
$$\frac{d^2\vec{R}}{dt^2} = a\hat{n} \qquad \text{Eqn. 3}$$

Where $\vec{R}$ = Position vector of any point along the liner

$\hat{n}$ = Inward unit normal to surface at that point

a = Acceleration

Equation 3 is equivalent to the assumption that strength effects can be ignored in the collapse of the liner.
The motion equation (3) cannot be solved in closed form, because $\hat{n}$ is a function of time and is not known explicitly. The equation can be solved numerically however by dividing the liner surface into a mesh of nodal points, integrating the equation for each node over a small time step, δt, and assuming that $\hat{n}$ is constant over the step. The new node positions can then be used to compute a new $\hat{n}$ at each succeeding point and we can then integrate the equations for another time interval δt. The foregoing development is less restrictive than the more traditional one dimensional liner collapse theories (Ref. 3), in that it makes no assumption about the shape of the collapse. For example a common assumption made about the contour is that it obeys Taylor's relation:



$$\sin \delta = \frac{V_o}{2\,\mu_d} \qquad \text{Eqn. 4}$$

<u>Figure 8 Taylor's Relation</u>

Where δ = Collapse angle

V_o = Collapse velocity

μ_d = Detonation wave speed

This is equivalent to saying that the liner does not undergo any stretching relative to the tangent to the liner surface, i.e. no net shear flow. However, in charges that experience a gradient in the collapse velocity, V_o , along the liner, such an assumption is not warrented (Ref. 4).

2) Primary Jet Formation When segments from both sides of the collapsing wedge meet, a high velocity jet is formed. It is assumed that a stagnation point is formed at the position where the collapsing sides meet. For a frame of reference attached to the stagnation point, and under the assumption that an incompressible, steady flow is established, it will appear that all liner material flows into and out of this point with some velocity, V_t . For a fixed reference frame, however the flow will appear to originate at some point A and collapse with a velocity V_c until it undergoes collision at some point B. In the stagnation point frame of reference, this is equivalent to having a particle flowing from A to a point C (which is the stagnation point) at a velocity V_f, and then the stagnation point C moving to point B with a velocity V_s (see Figure 9).

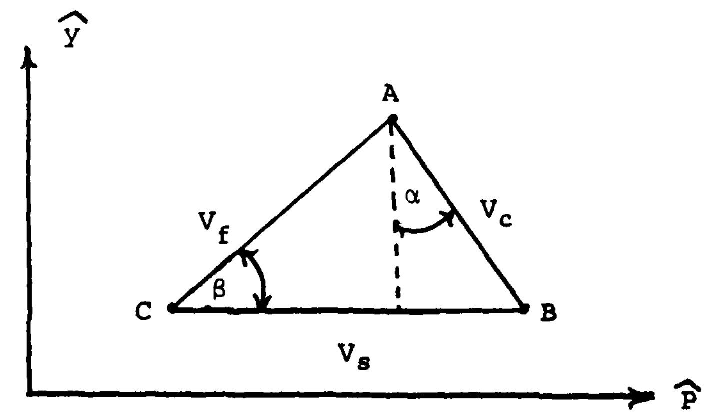


Figure 9. Frame of reference attached to the stagnation Point C.

Trigonometric considerations from Figure 9 will show that:

$$\tilde{V}_f = \left\{ |V_c| \frac{\cos \alpha}{\sin \beta} \right\} \left\{ -\cos\beta p - \sin\beta y \right\}$$

$$\tilde{V}_s = \left\{ |V_c| \left(\sin\alpha + \frac{\cos \alpha}{\tan \beta} \right) \right\} \hat{P} \qquad \text{Eqns. 5}$$

In equations 5, tan β is the slope of the collapsing liner contour at the stagnation point, while V_o and α can be computed from the equations of motion.

The jet velocity will be simply:

$$\tilde{V}_j = |V_f| \hat{P} + \hat{V}_s \qquad \text{Eqn. 6}$$

The equations developed above govern the collapse of wedge liners and the formation of sheet jets, i.e. star cone, shaped charge geometries (wedges arranged symmetrically about a common axis, and jets so formed from them). This model also departs from, and is a significant improvement over conventional models of shaped charge behavior in that:

1) Explosive gas pressure decay and gas/metal interaction submodels based only on the physical constants of the explosive and metals, were introduced.

2) Shear and extensional flow considerations for the collapsing wedge are included, i.e. Taylor's formula is eliminated.

3) Analytic Results The model of section B-2 and its mathemematical form (Eqns. 1-6) were programmed for solution on a computer. The resulting program, HYJETS, was then used to evaluate three liner geometries, two LSI designs and one design from reference 5. All liners were of copper and all were loaded with composition B explosive. Magnitudes of program input variables for each geometry are presented in Table II.

Table II. Input Variables for Hyjets Evaluatuion

No.	Title	$2\alpha_c$ (Deg)	$2\alpha_w$ (Deg)	h_s (mm)	L (mm)	h_e (mm)
1	Des.-3119 (Ref. 5)	109.5	90.0	2.0	14.1	55.9
2	Des.-LSI,7	60.0	50.0	1.575	59.6	140
3	Des.-LSI,1	90.0	60.0	1.575	50.0	177

Where:
$2\alpha_c$ = Cone angle
$2\alpha_w$ = Wedge angle
h_s = Liner thickness
L = Cone length
h_e = Explosive height above cone apex.

Figures 10,11 and 12.- Plots of the HYJETS predicted collapse of these star cones.
The incoming sheet jets are now treated as collapsing liners, and it is noted that the dynamic angle, β from our jet formation development, is approximately 90°. However, since jet velocity increases as $1/\tan\beta$ little amplification of the jet velocities of the incoming sheet jets can be expected. It is obvious that smaller initial cone angles ($2\alpha_c$)

are required to achieve significant velocity amplification. This conclusion is supported by the experimental work of Gerger and Honica, (Ref. 5). They experimentally measured secondary jet velocities from liner cones of various angles, and their results, along with LSI-designs data, are presented in Table III.

Table III. Comparison of HYJET generated Primary jet velocities and Experimentally generated Secondary Jet Velocities.

	Cone Angle $2\ \alpha_c$ (Deg.)	HYJETS Sheet jet Velocity (km/sec)	Experimental SJP jet tip velocity (km/sec)
DES-2745	56	*	6.6
DES-LSI,7	60	4-9	*
DES-2743	72	*	6.1
DES-LSI,1	90	4-7	*
DES-2570	90	*	5.0
DES-3119	109.5	2-4	4.5

* Not Applicable

References for section B, Design Analysis

1. Kennedy, J. E., "Explosive output for Driving metal", 12th symposium on the behavour and utilization of explosives in Engineering Design, University of New Mexico, 1972.

2. Hoskins, N.E., et al, "The motion of plates and cylinders driven by detonation waves at tangential incidence", Fourth symposium on detonation, U.S. Naval Ordnance Laboratory, Silver Springs, Md., 1965.

3. Pugh, E.M.,et al, "Theory of jet formation of charges with lined conical cavities", Journal of applied physics, 23 May, 1952.

4. Randers-Pehrson, G., "An improved equation for calculating fragment projection angles", Second international symposium on ballistics.

5. Gerger, W. and Honica, G., "Shaped charges with pyramedal liners, "Battelle-Institute, Germany.

PYRAMID, TYPE 3119, Battelle Inst.

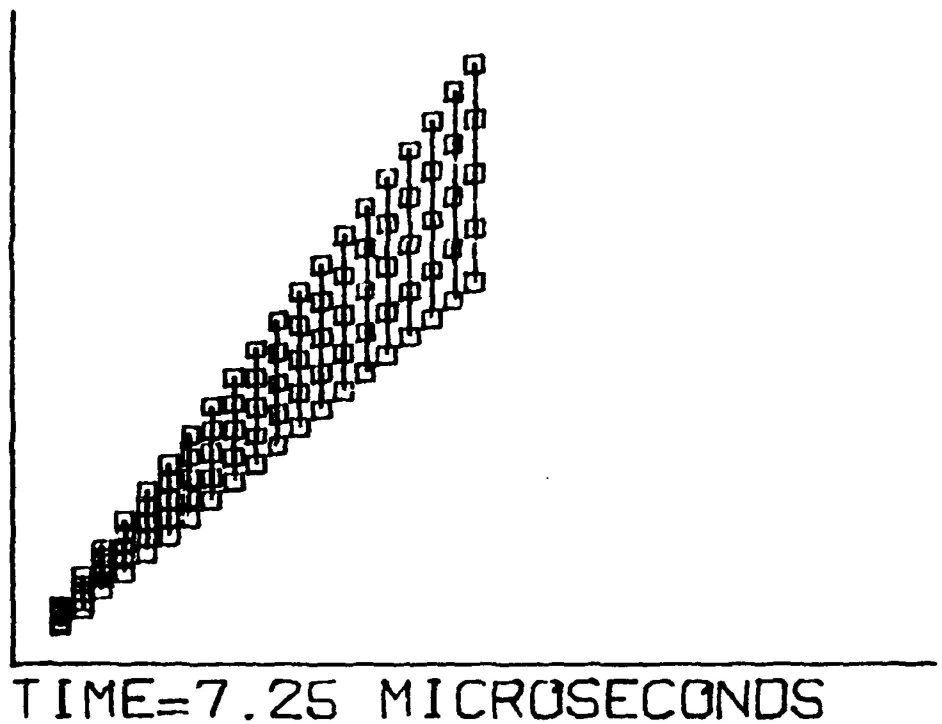


Figure 10.a

PYRAMID, TYPE 3119, Battelle Inst.

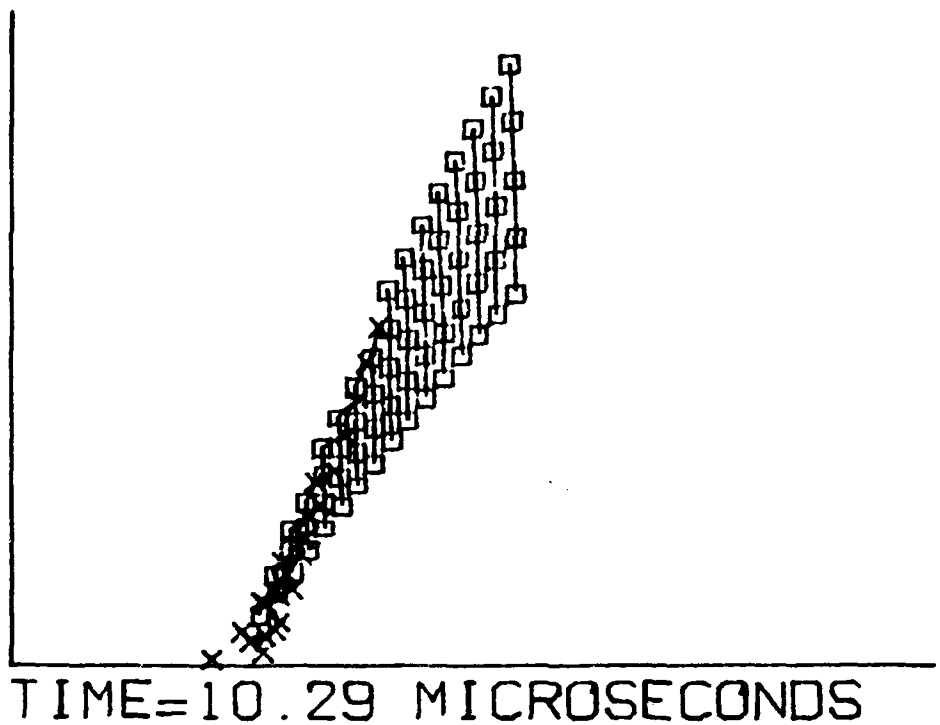


Figure 10.b

PYRAMID, TYPE 3119, Fattelle Inst.

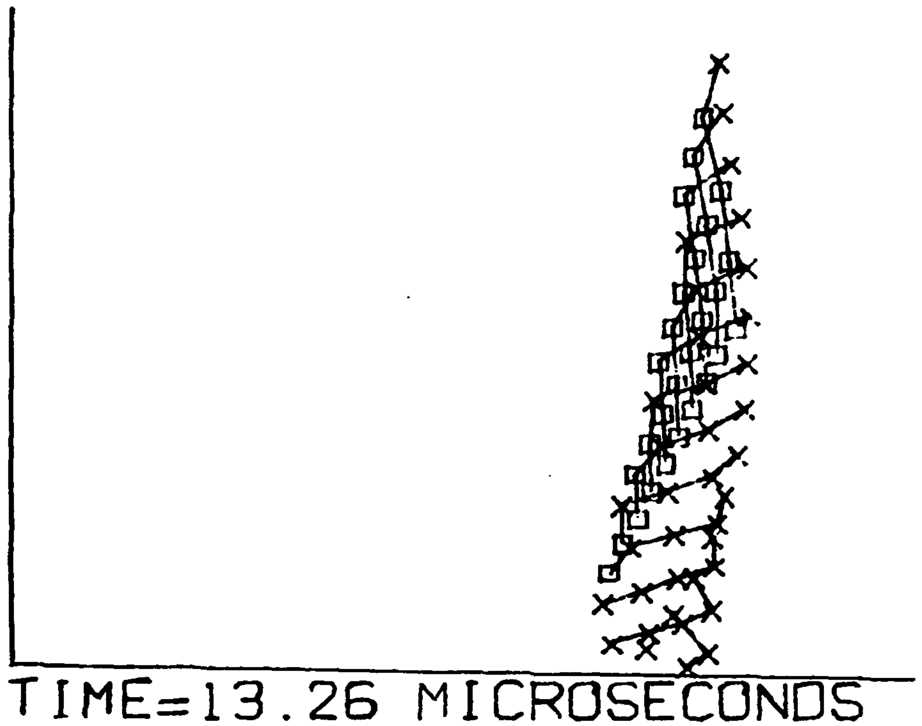


Figure 10.c

PYRAMID, TYPE 3119, Battelle Inst.

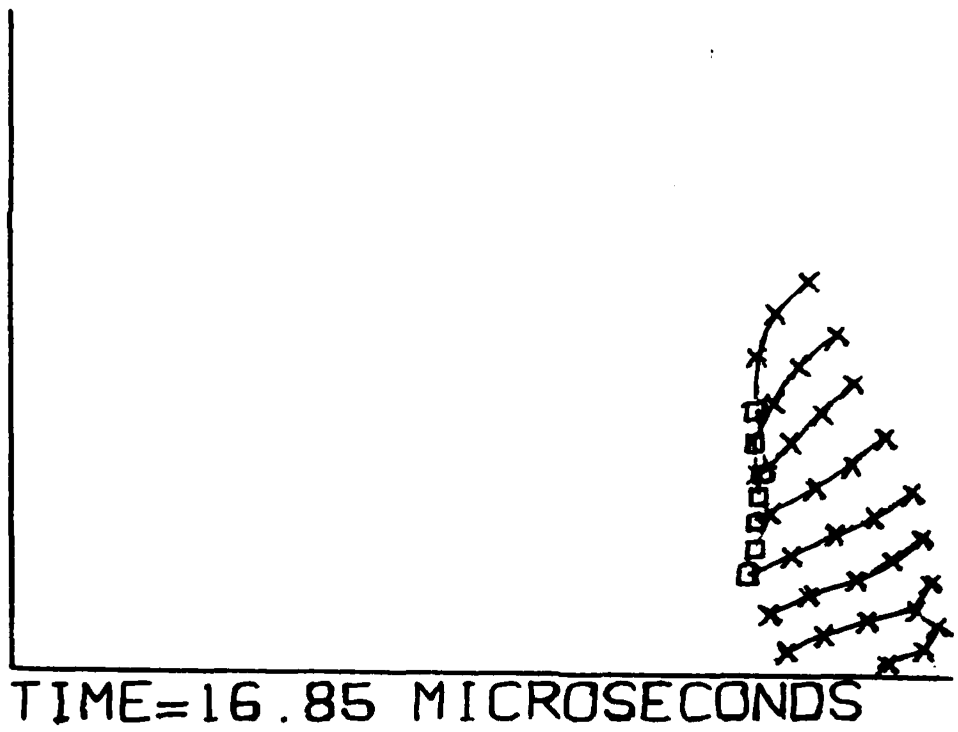


Figure 10.d

LSI DESIGN-7, CONE = 60, WEDGE = 50

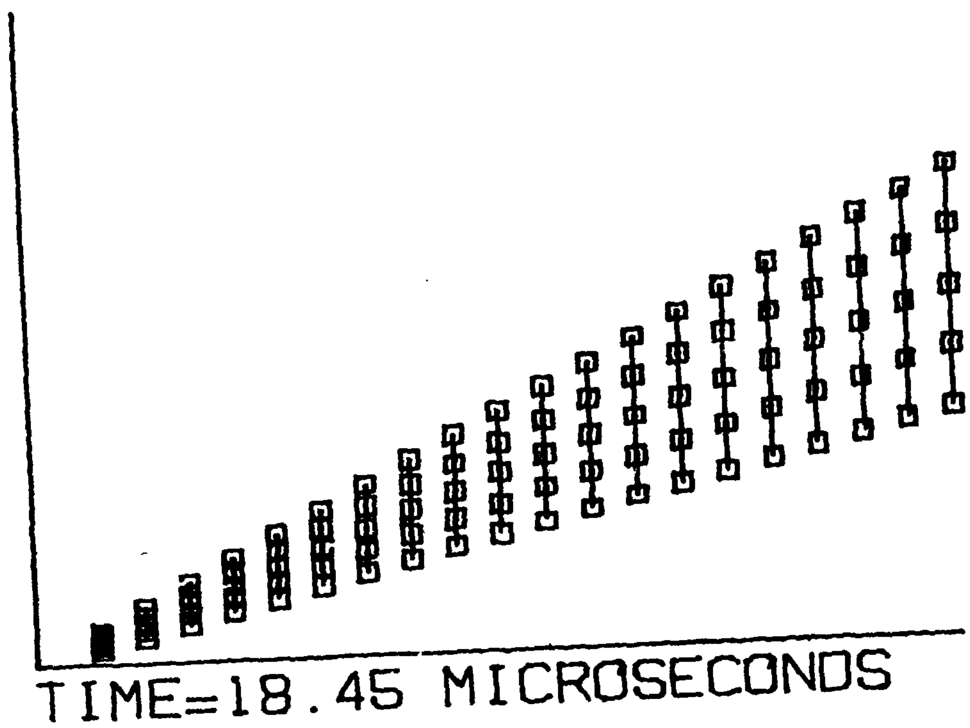


Figure 11.a

LSI DESIGN-7, CONE = 60, WEDGE = 50

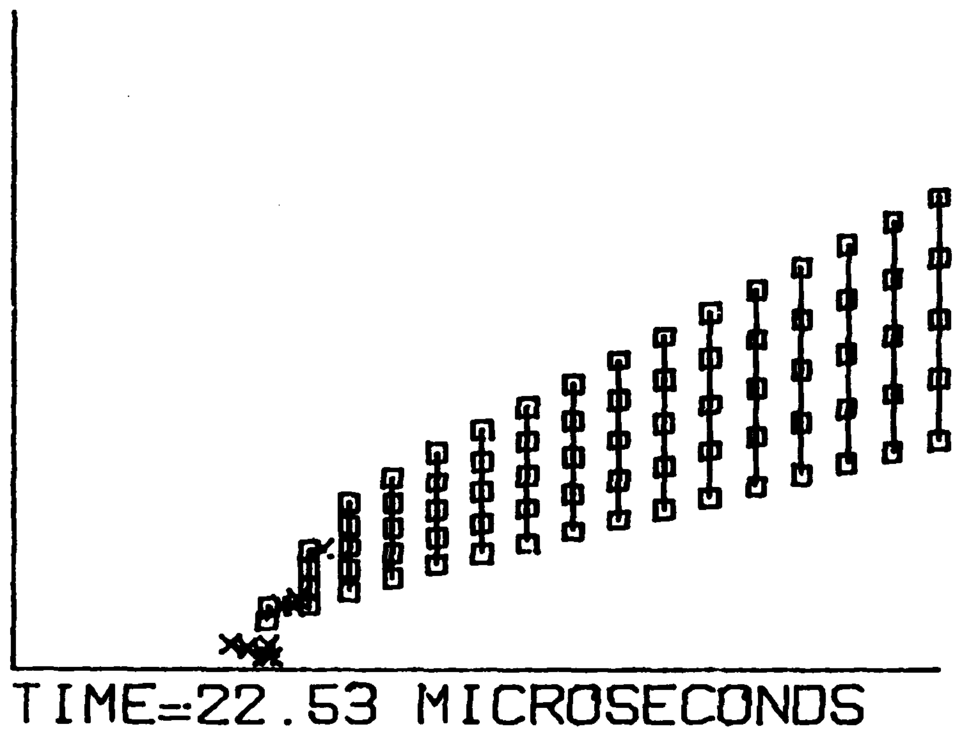


Figure 11.b

LSI DESIGN-7, CONE = 60, WEDGE = 50

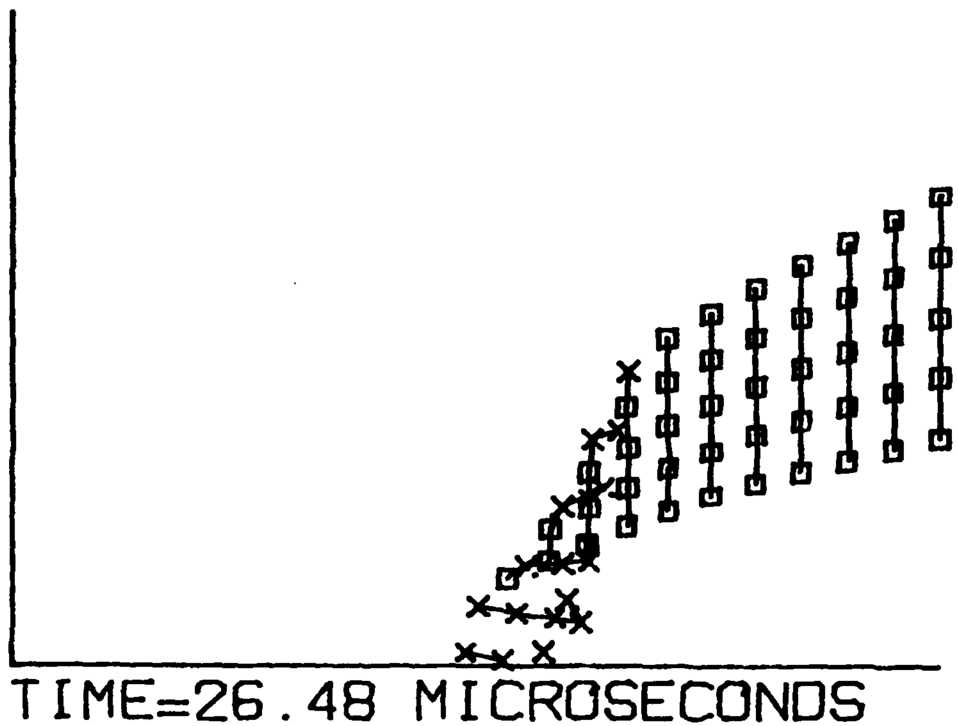


Figure 11.c

LSI DESIGN-7, CONE = 60, WEDGE = 50

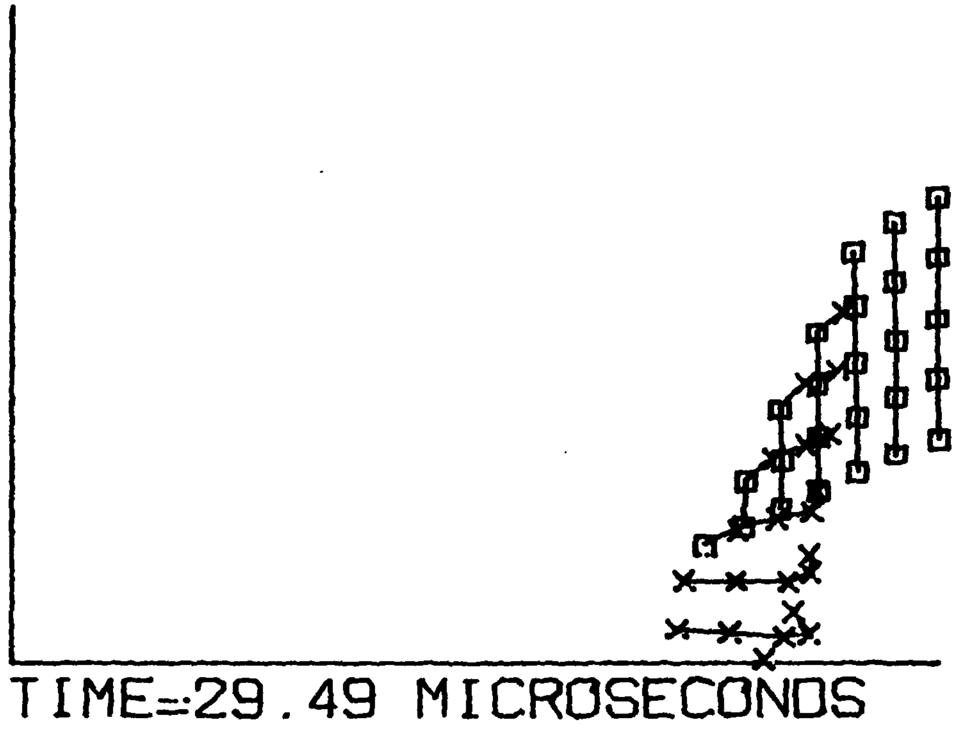


Figure 11.d

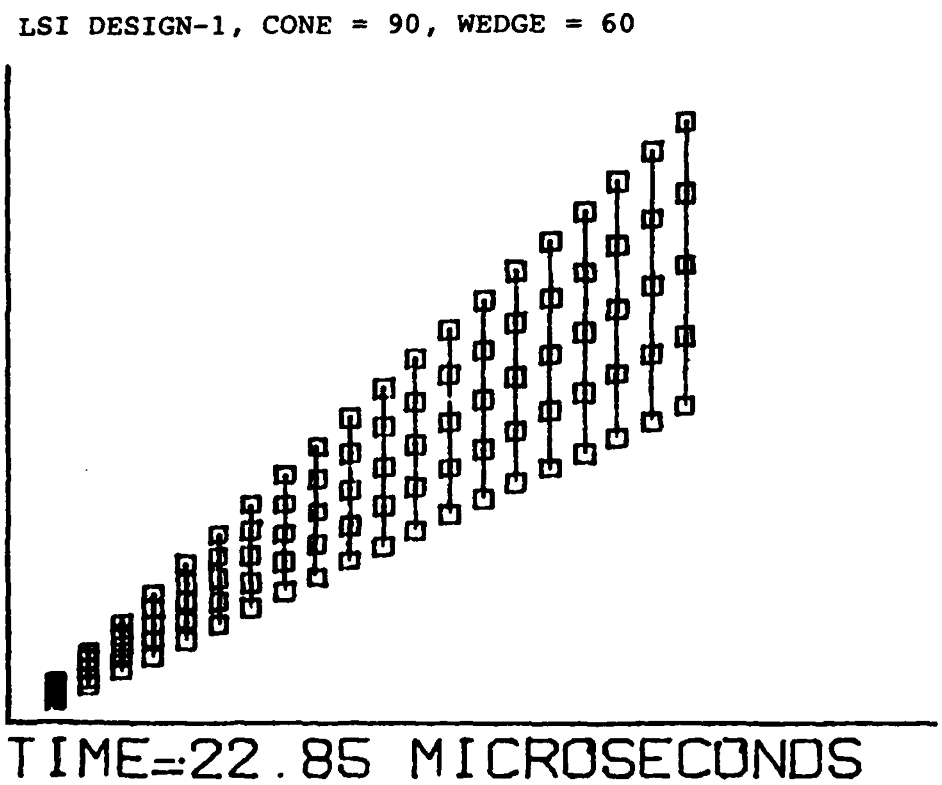


Figure 12.a

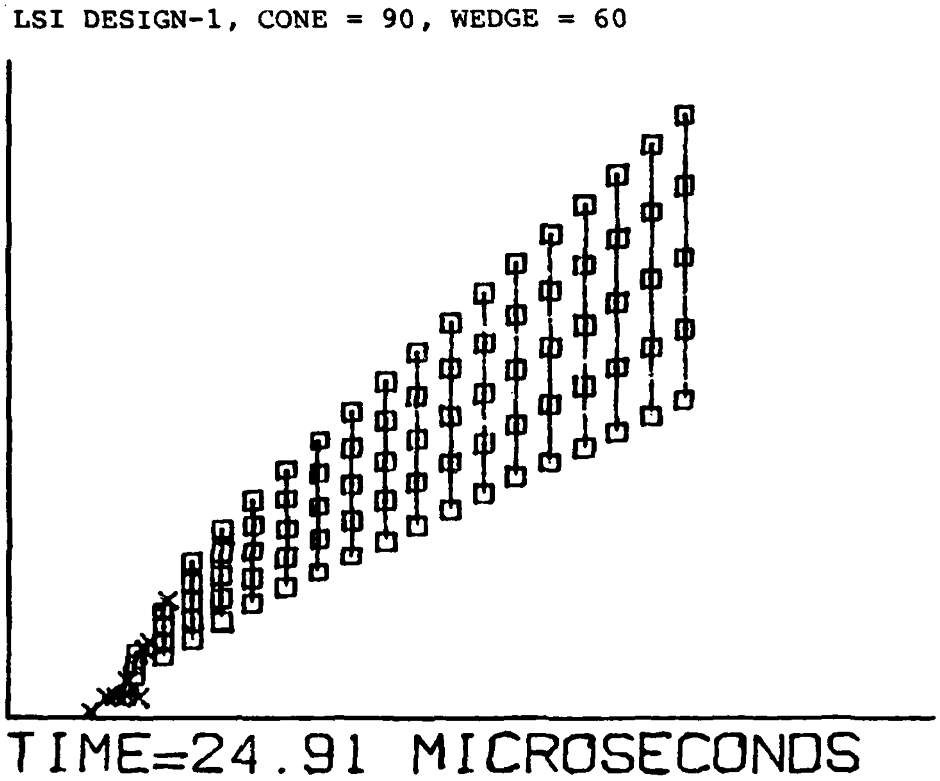


Figure 12.b

LSI DESIGN-1, CONE = 90, WEDGE = 60

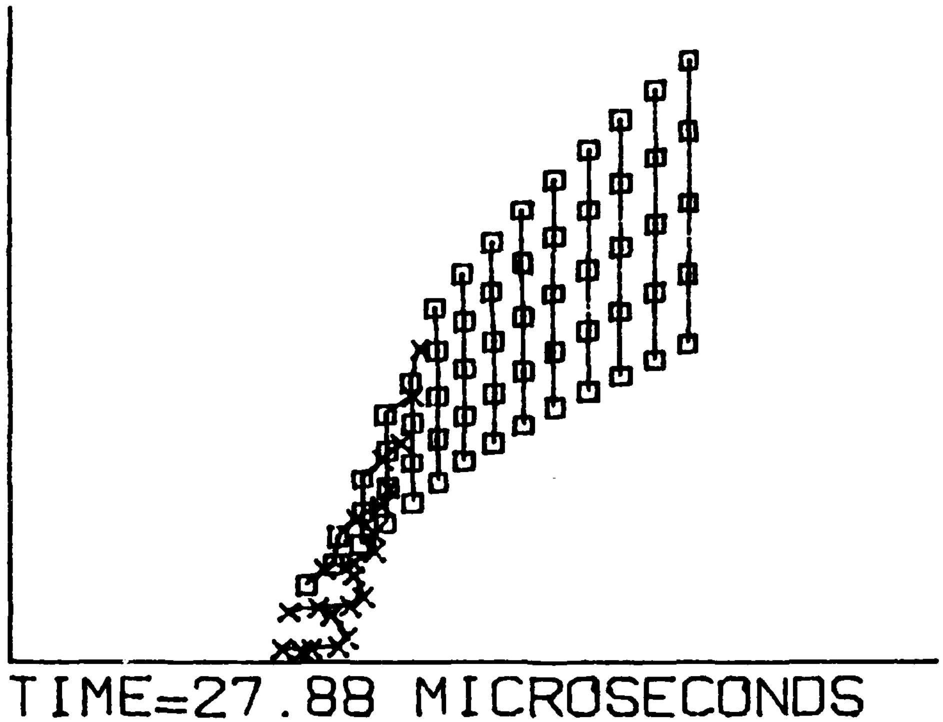


Figure 12.c

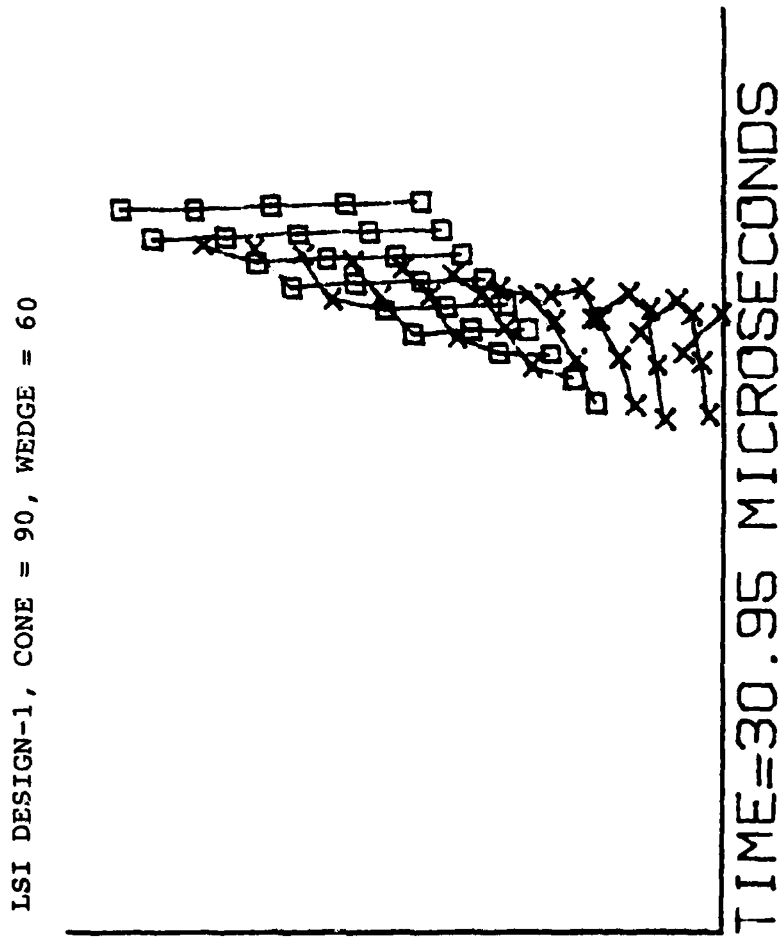


Figure 12.d

SECTION C

MANUFACTURING

C. MANUFACTURING

1) Process Analysis The star-cone liners selected on the basis of the design analysis phase (section B of this report) were reviewed and modified for producibility. It is, of course, essential that the manufacturing method ultimately selected would represent the most inexpensive procedure which also maintains the required design precision. Therefore, a producibility study was initiated on a star-cone, base line design (Figure 13). This study involved the evaluation of various available processes for producing the star-cone liner in limited quantities. These are presented along with process characteristics in Table IV. The following discussion highlights major advantages, disadvantages and features of all (or selected) processes evaluated.

Liner Material Considerations The tensile strength of hard-drawn copper is about 50,000 to 70,000 lb/in^2 and the elongation is from 4 to 11 percent, depending upon the degree of drawing. In the annealed conditions, the strength varies from 35,000 to 40,000 lb/in^2 with an elastic limit of 20,000 lb/in^2. Copper is thus very malleable and ductile.

1-1 Tool Room Machining Operations

Soft copper items of intricate shapes as the "star" liner do not lend themselves to this operation for the following reasons:

A. High cost (machine time)

B. Surface finish obtained with cutting tools is unacceptable.

C. Part fragility (as machining progresses)

D. Difficult to maintain tolerances

E. Inability to produce matching or similar geometrics, cone-to cone (duplication)

1-2 Cold or Hot Forming Processes

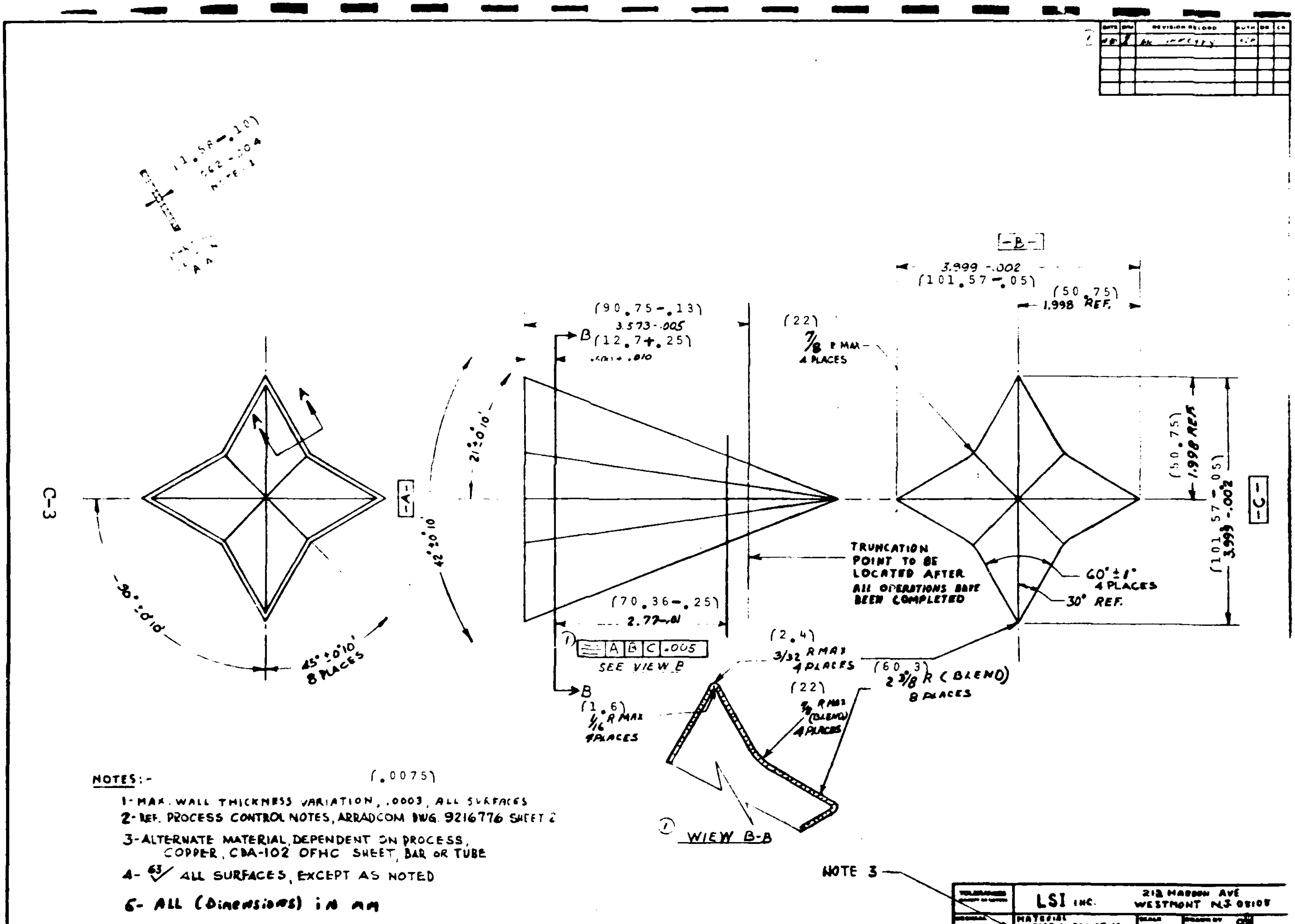
A. Small sample quantity does not justify initial, high die costs.

PROCESS \ PROCESS CHARACTERISTICS	Costs	Surface Finish	Part Fragility	Tolerance Maint.	Reproducibility	Compatability	Die Complexity	Metal Flow	Overall Process Complexity
Machining	1	1	1	2	1	2			2
Cold/Hot Forming	1	3	2	3	3	3	1	2	2
Magna Forming						1			
Impact Extrusion	1	3	2	1	2	2	2	2	2
lectro-Deposition	1	1	3	1	1	2			1
Chemical Vapor Dep.	1	1	3	1	1	2			1
Mechanical sizing	2	3	3	2	2	3	2	2	2
Bulging	2	3	3	3	3	3	3	3	3

<u>Numerical Evaluation Scale</u>

1 · Unacceptable to Poor
2 - Fair to Average
3 - Average to Very Good

Table IV , Comparative Assessment of Available Processes for Producing Star Cone Copper Liners in Limited Quantities



-A-
-B-
-C-
3.999 -.002
(101.57 -.05)
(50.75)
1.998 REF.
(90.75 -.13)
3.573 -.005
(12.7 +.25)
(22)
7/8 R MAX
4 PLACES
21°±0°10'
42°±0°10'
90°±0°10'
45°±0°10'
8 PLACES
(70.36 -.25)
2.77 -.01
A B C .005
SEE VIEW B
TRUNCATION POINT TO BE LOCATED AFTER ALL OPERATIONS HAVE BEEN COMPLETED
60°±1°
4 PLACES
30° REF.
(2.4)
3/32 R MAX
4 PLACES
(60.3)
2 3/8 R (BLEND)
8 PLACES
(22)
7/8 R MAX (BLEND)
4 PLACES
(1.6)
1/16 R MAX
4 PLACES
VIEW B-B
NOTES:-
(.0075)
1- MAX. WALL THICKNESS VARIATION, .0003, ALL SURFACES
2- REF. PROCESS CONTROL NOTES, ARRADCOM DWG. 9216776 SHEET 2
3- ALTERNATE MATERIAL, DEPENDENT ON PROCESS, COPPER, CDA-102 OFHC SHEET, BAR OR TUBE
4- 63 ALL SURFACES, EXCEPT AS NOTED
6- ALL (DIMENSIONS) IN MM
NOTE 3
LSI INC.
212 MADDON AVE
WESTMONT NJ 08108
MATERIAL
COPPER SHEET, OFHC.
.005
1-1
CONE, SJP, DESIGN-2
4-28-80
C-29150-J

Figure 13

1-3 Magnaform

A. The "star shaped" liner is not considered a "body of revolution" due to its "interrupted" interior and exterior contours. Other similar processes were therefore not considered in this evaluation.

1-4 Impact Extrusion

A. Small sample quantity does not justify initial high tooling costs.

B. Difficult to maintain uniform wall thickness.

1-5 Electro-Deposition (Plating, etc.)

A. Wall thickness variations are obtained because of intricate, sharp pointed contours.

B. Costly machining and finishing operations required after plating.

1-6 Chemical Vapor Deposition

A. Costly machining and finishing operations after plating.

1-7 Mechanical Sizing

"Sizing" an available, standard, copper shaped charge liner of proper dimensions in a sizing punch and die as shown in Dwg. No. C-29156-J (Figure14). The "sizing" or "forming" tools can be made by alloy steel, heat treated to RC-38-42 before machining. This will maintain tooling cost at a minimum. Since the wall thickness is fixed on the standard cone, the resulting "bending" of the outside periphery will maintain the original wall thickness characteristics.

1-8 Bulging

This procedure, along with mechanical sizing, is discussed in more detail below. Bulging is treated extensively in Engineering Materials and Processes, 3rd Edition, Clapp and Clark.

Considering just cost considerations alone, mechanical sizing, and bulging appear to be the only two candidate processes for further consideration.

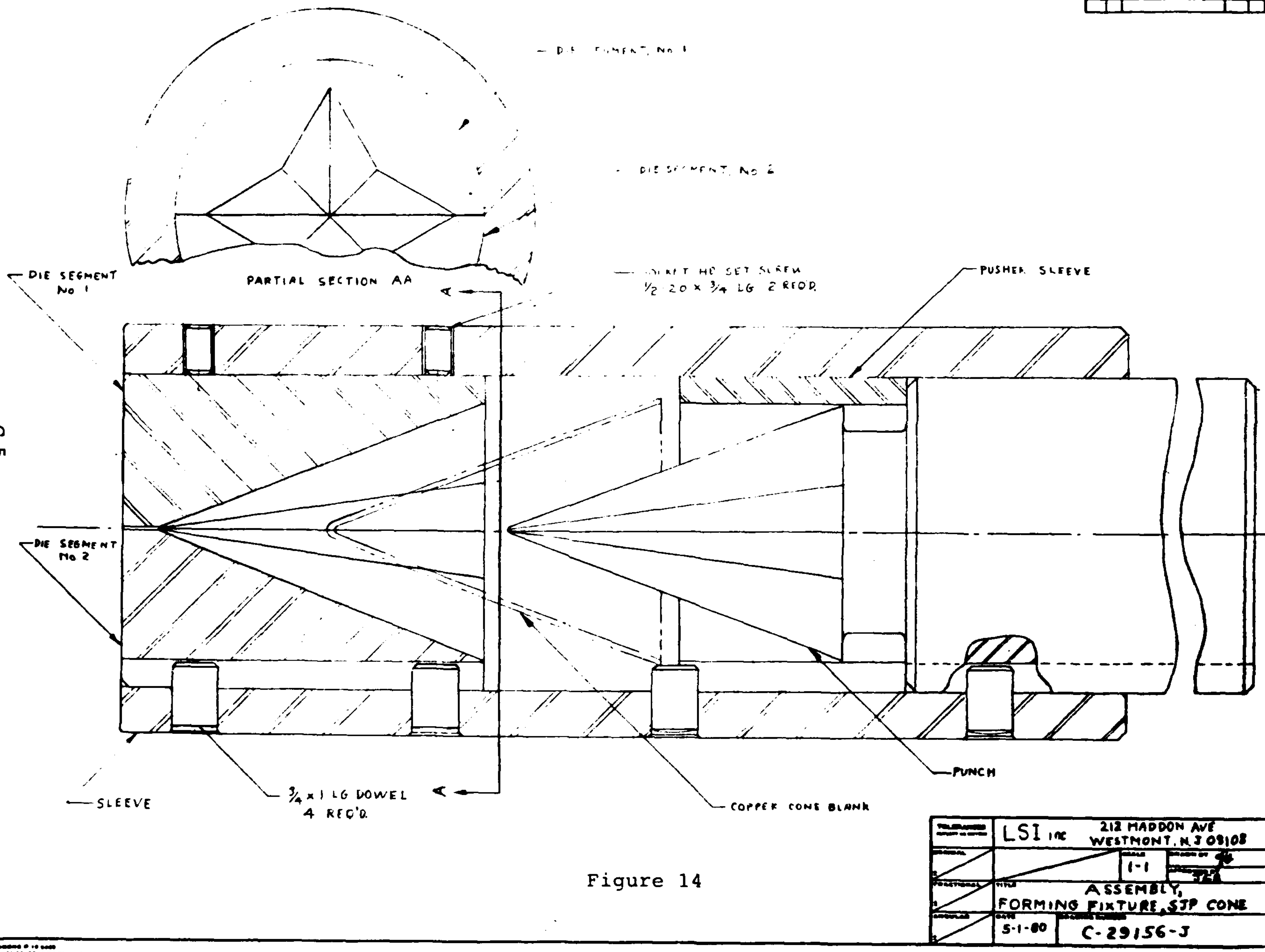

DIE SEGMENT No 1
PARTIAL SECTION AA
DIE SEGMENT No 2
1/2-20 x 3/4 LG 2 REQ'D
PUSHER SLEEVE
SLEEVE
3/4 x 1 LG DOWEL 4 REQ'D
COPPER CONE BLANK
PUNCH
LSI INC 212 MADDON AVE WESTMONT, N.J 08108
1-1
ASSEMBLY, FORMING FIXTURE, SJP CONE
5-1-80
C-29156-J

Figure 14

Items with bulged and/or assymetric configuration such as shown in Figure 13 can be produced using the "Bulging" process. The work is done with special dies in a press by means of either a fluid bulging die or a rubber bulging die. For both of these operations, a cup shown in Figure 15(a) is produced in a normal drawing press, preparatory to the bulging operation.

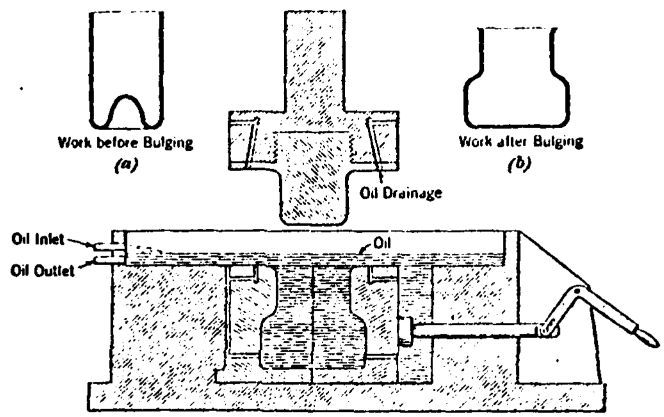


Figure 15 Punch and Die Used in Bulging Process

The cup is placed in a die, as shown in Figure 15(c), and is filled with oil. The plunger is forced down into the oil with sufficient pressure to make the metal conform to the configuration of the die. The bulged article is withdrawn by sliding one half of the die to one side. The method of bulging by means of rubber is shown in Figure 16. In this process, after the cup is placed in the die, the plunger forces the cup downward and simultaneously squeezes the rubber outward, making the material take the shape of the die.

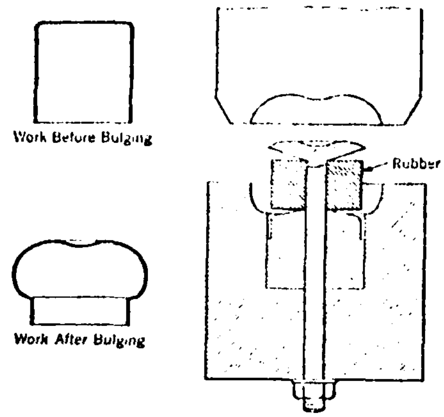


Figure 16 Bulging Process

In the case of producing the star liner using the "Bulging" process, a simple inversion of the bulging technique as shown in Figure 16 is used. Refer to Dwg. No. C-29157-J (Figure17) assembly, star liner, rubber bulging fixture; an alloy steel punch machined to the desired interior star liner configuration is positioned in a heavy walled cylinder. A standard, copper, shaped charge liner of proper dimensions is placed on the alloy steel punch over which a pre-formed rubber (30-40 durometer) medium (fluid) is positioned. When the ram of the press acts on the rubber medium, the soft walls of the standard charge cone will be forced or bulged inwardly on the punch thereby configuring the interior star liner. There will be no reduction of the copper metal, only a simple, multi-faceted, bending process.

This system of "Bulging" is preferred over the "Sizing" procedure and was selected for further work because of the following reasons:

A. Tooling costs are reduced. The intricate, 2-piece die is eliminated and replaced with an inexpensive rubber medium.

B. There is no internal metal flow in the bulging process.

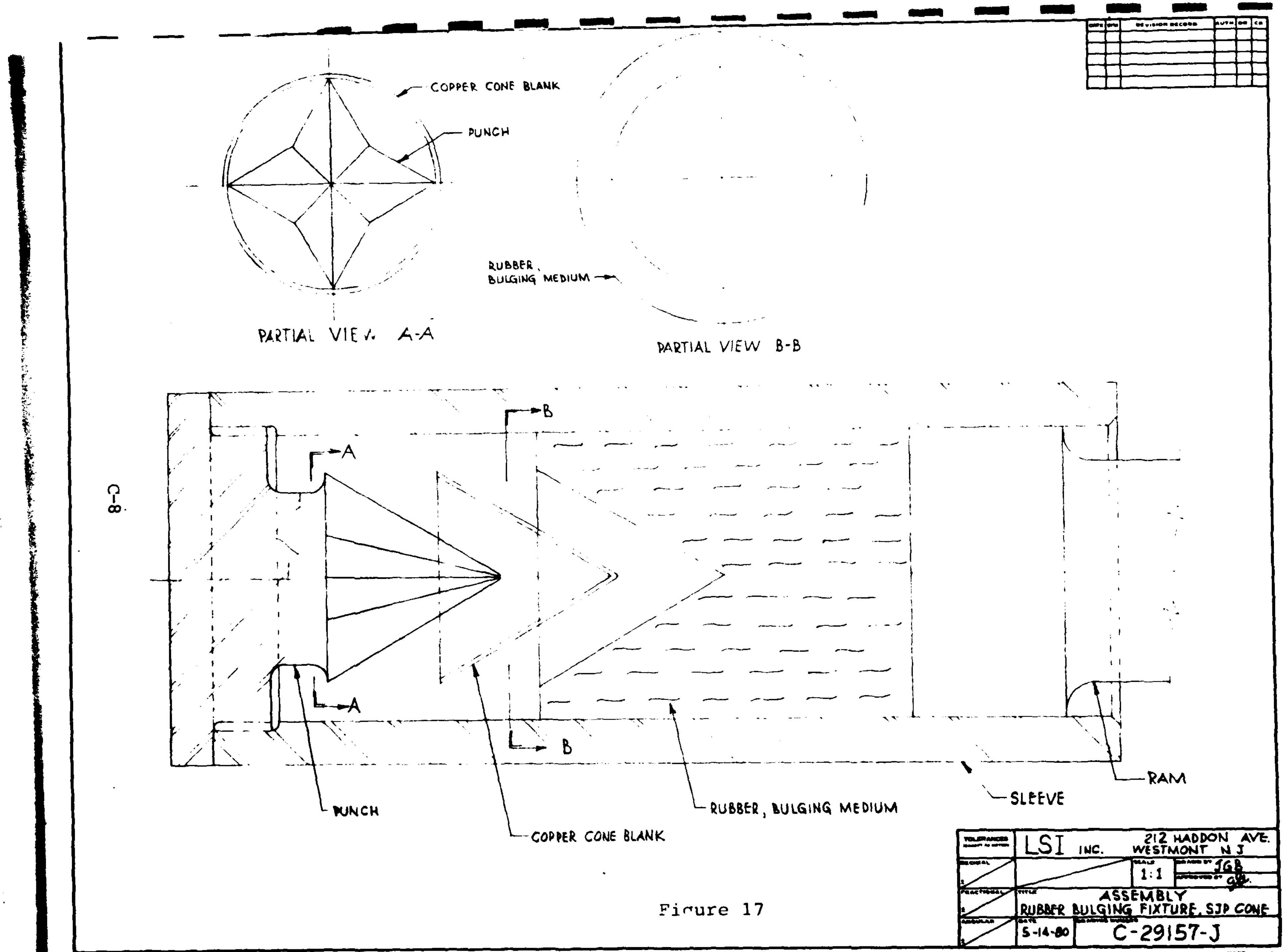

COPPER CONE BLANK
PUNCH
RUBBER, BULGING MEDIUM
PARTIAL VIEW A-A
PARTIAL VIEW B-B
B
A
PUNCH
COPPER CONE BLANK
RUBBER, BULGING MEDIUM
SLEEVE
RAM
LSI INC.
212 HADDON AVE.
WESTMONT N J
1:1
JGB
ASSEMBLY
RUBBER BULGING FIXTURE, SJP CONE
5-14-80
C-29157-J

Figure 17

The sizing process involves a translational motion of the standard copper cone along the length of the die as well as translational motion of the punch on the interior of the star liner as it is being formed, thereby resulting in metal flow. Also, the punch and die must be precisely keyed radially to guarantee angular tolerance integrity.

C. Use of the rubber bulging process should result in an acceptable product, free from surface defects and dimensionally acceptable.

Of course, large quantity production of star liners will necessitate an in-depth study of all available manufacturing processes in order to achieve cost effectiveness.

2) The Bulging Technique Based upon computerized simulation tests, several condidate Hyperjet designs were selected for manufacturing and tests. To facilitate manufacturing, the bulging process (as discussed in Section C-1) was selected. This process utilizes a standard liner as the "pre-formed Hyperjet liner blank". An acceptable range of wedge angles of between 40° and 80° was established to ensure the formation of substantial primary jets and to provide angles varying between 40° and 100° for the formation of secondary jets.

In order to establish a point of reference and comparison, two designs rather than a single design within the above parameters were selected for manufacturing and eventual testing. Standard GFM liners with cone angles of 42° and 60° were made available to be used as Hyperjet blanks. As experimental test data from these blanks was expected to be available, extrapolations from them could be used to simulate the performance of cone angles over the range of 42° and 90°.

Accordingly, samples of the GFM hardware (liner blanks) were received by LSI and include the following items:

- 5- 42° copper cones
- 2- 60° copper cones
- 1- Test fixture

Each of the above mentioned designs used in the bulging studies have wedge angles of 60°, established as the minimum angle necessary to insure the formation of a cohesive subsonic primary jet; cone angles below 90° are necessary since, at higher angles, stagnation point velocities are too modest to result in significantly amplified secondary jet velocities.

On receipt of ARRADCOM approval (11 July 1980) of the bulging manufacturing procedure for either or both of the 42° and 90° cones, a purchase order was placed with Kustom Precision Machine Products, Inc., Oreland, Penna. for the manufacture assembly and delivery of the following items:

- 3 each DWG C-29150-J (42°) cones
- 3 each DWG C-29159-J (90°) cones
- 6 each-Test Body
- 6 each-Test Booster Holder
- 6 each-Test Retainers
- 1 each-Test fixture consisting of the following:
    - 42° punch
    - 90° punch
    - Sleeve
    - Ram
    - Platen
    - Rubber Bulging Components - (42°)
    - Rubber Bulging Components - (90°)

Some delays were encountered with these items upon receipt. Purchased material for the sleeve as received did not meet specified concentricity requirements. Replacement parts had to be reordered. In order to expedite manufacturing, an attempt was made to recut the sleeve interior surface to improve concentricity. This operation provided acceptable concentricities; however, wall thickness were reduced below .500 inches, which had been determined to be the minimum tolerable thickness under anticipated pressure-loading developed during the bulging process. Replacement parts were therefore ordered. Also, deliveries of rubber components for the LSI bulging process had to be extended due to the small-quantity requirements. Suppliers would only manufacture low-quantity items on a non-interference basis with other orders.

An intensive engineering/fabrication effort was conducted to prove out the manufacture of the more complex parts to be used in the LSI bulging process. Difficulties were initially encountered in obtaining acceptable rubber bulging mediums, first from a supply point of view, and then technically. For ease of forming, and to minimize medium stretching, rubber parts were molded to the general configurations of the 42° and 90° cones. Several attempts were required until acceptable parts were obtained; expansion taps, and air evacuation (bleeder) ports were consecutively added to molding equipment in order to first resolve a disassembly problem and secondly to eliminate air bubbles in the rubber medium.

Set-up mandrels (42° and 90° punches) were required in order to verify machine settings and procedures for cutting precision mandrels. This first set of mandrels was machined from aluminum stock. The parts were continually corrected and modified as machine settings were adjusted to obtain exact contours, and consequently the finished aluminum mandrels were not useable for liner fabrication due to numerous surface imperfections. Final steel mandrels were subsequently machined.

At this stage of the bulging study, manufacture of the 42° Hyperjet design (i.e., drawing #C-28150-J, or Figure13) was begun, and a change was made for the second design, i.e. previously a 90° liner design, dwg. #C-29159-J (Figure18) to a 60° liner design, dwg. #C-29154-J (Figure19). This change was made in order to minimize further manufacturing difficulties, most of which had been previously resolved. GFM material originally supplied included only 42° and 60° liner blanks, and all of the anticipated manufacturing problems had been resolved on the 42° design. It was initially planned to first reform the 60° liner blanks to a 90° configuration prior to manufacturing in the LSI bulging fixture. This change involves eliminating the reforming process for the 60° liner blanks, and using these blanks to manufacture 60° Hyperjet liners in order to avoid introducing additional problems into the manufacturing process.

The first attempts to manufacture Hyperjet liners via the bulging process were conducted with a high degree of success. Three 42° Hyperjet liners were manufactured and inspected. All of the completed liners exhibited excellent symmetry and acceptable dimensions through most of the liner length, principally in the center area of the cone. Some deformation was encountered at the apex of the cone, which is simply cropped and capped in the final assembly. At the other end, poor forming qualities were exhibited in a zone approximately 38mm from the front of the liner. This problem occurs as a result of bulging medium seepage over the end of the cone, and consequently, insufficient forming pressures applied in this area. A lead base (stop), capping the front of the mandrel and cone, was added to the bulging fixture to resolve this problem.

During this initial manufacturing phases all of the GFM 42° dragon liners (see attached inspection report) were expended in process testing and consequently additional dragon liners

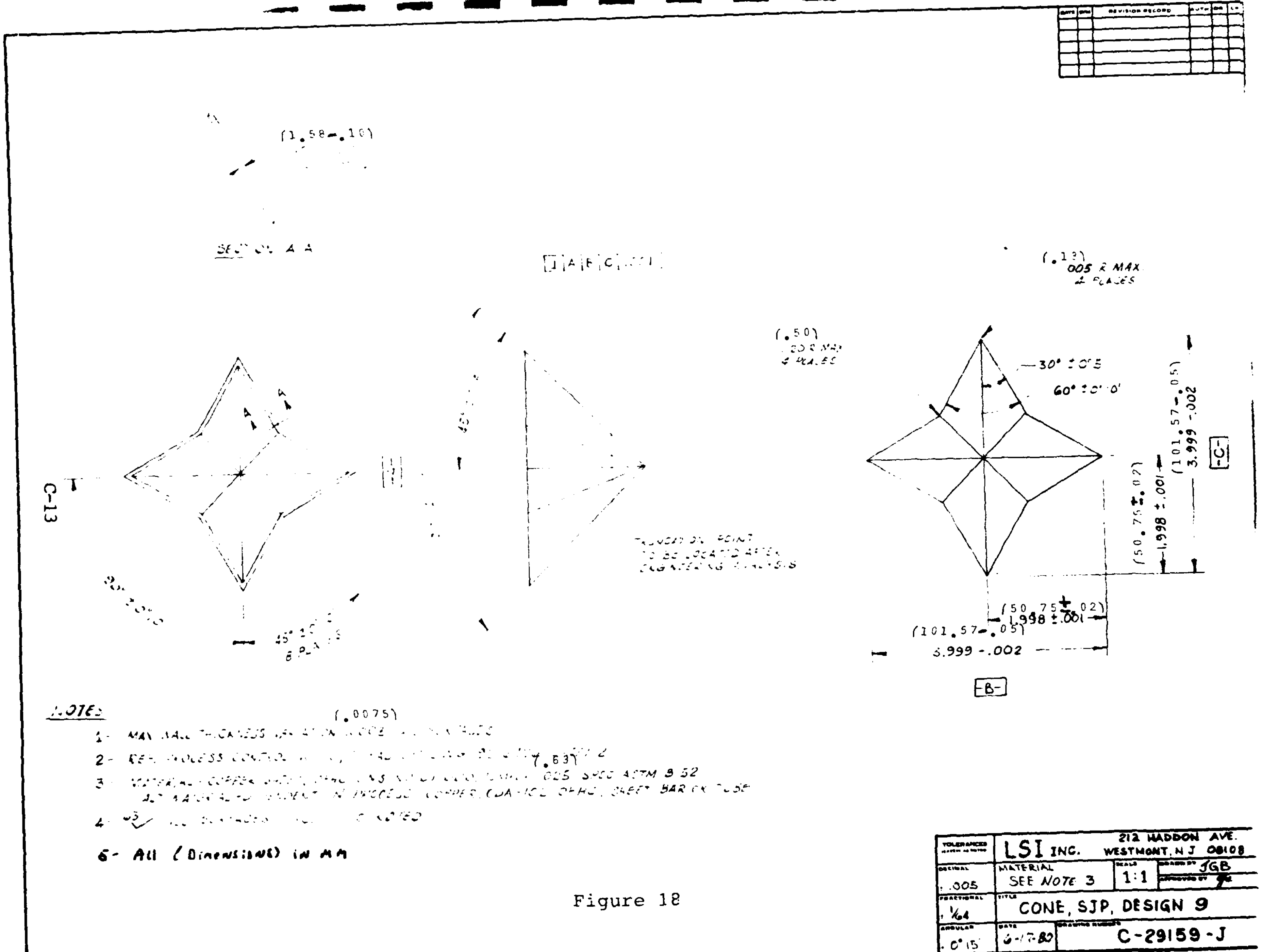
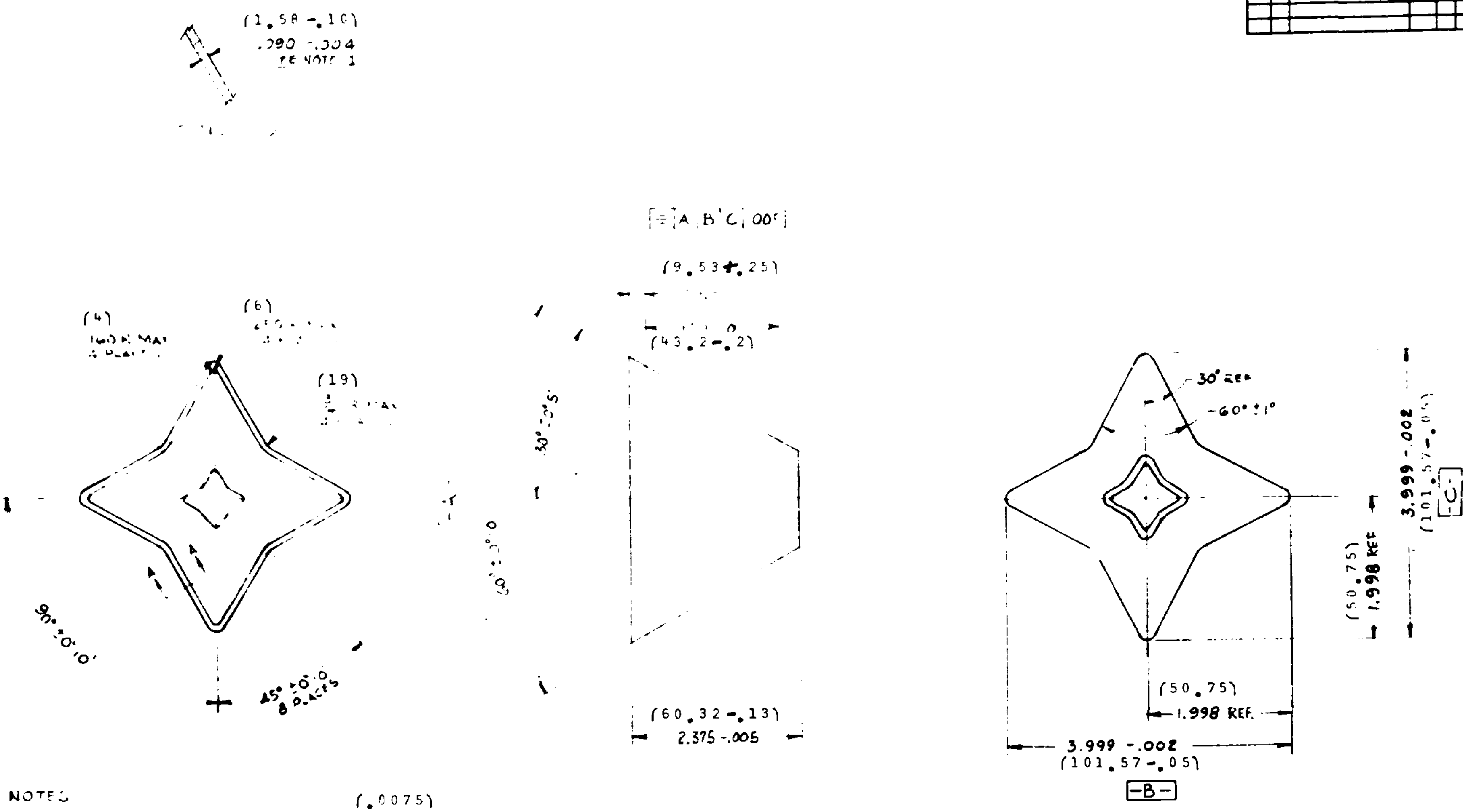

(1.58-.10)
SECTION A-A
(.13)
.005 R MAX
4 PLACES
(.50)
.020 R MAX
4 PLACES
30° ±0°5'
60° ±0°0'
TRUNCATION POINT
TO BE LOCATED AFTER
ENGINEERING ANALYSIS
(101.57-.05)
3.999 -.002
(50.75±.02)
1.998 ±.001
-B-
-C-
NOTES
(.0075)
(.63)
.005 SPEC ASTM B 52
6- All (DIMENSIONS) IN MM
LSI INC.
212 HADDON AVE.
WESTMONT, N.J. 08108
MATERIAL
SEE NOTE 3
1:1
JGB
.005
1/64
0°15'
CONE, SJP, DESIGN 9
6-17-80
C-29159-J

Figure 18



NOTES

1 MAX WALL THICKNESS VAR ... .0003 ALL SURFACES (.0075)
2 REF. PROCESS CONTROL NOTES ... DWG 9216 ... SHEET 2 (.63)
3 MTL. COPPER SHEET OFHC UNS NO. C1 0200 TEMPER .025 SPEC ASTM B152
ALT. MTL. DEPENDENT ON PROCESS COPPER CDA 102 OFHC SHEET BAR OR TUBE
4 ALL SURFACES, EXCEPT AS NOTED
5 ALL (DIMENSIONS) IN MM

TOLERANCES	LSI INC.	212 HADDON AVE WESTMONT, NJ 08108	
DECIMAL ±.005	MATERIAL SEE NOTE 3	SCALE 1:1	DRAWN BY JGB / APPROVED BY AJE
FRACTIONAL ± 1/64	TITLE CONE, SJP, DESIGN 6		
ANGULAR ± 0°15'	DATE 5-14-80	DRAWING NUMBER C-29154-J	

Figure 19

were requested from the Government. Due to unavailability of these liners at ARRADCOM LSI was directed to a commercial source, The Firestone Tire and Rubber Company, for further supply. A purchase order for 10 dragon liners (ref. invoice #22924) was issued by LSI, and delivery was subsequently received. The lead base added to the 42° precision mandrel to redirect the rubber bulging medium in an axial direction, and to increase pressures at the liner mouth (base), was partially successful, with the degree of distortion (warpage) somewhat relieved. To further improve the condition, a two-step manufacturing process was set up, whereby liner blanks were partially formed without the lead base addition to the mandrel. A milling operation then followed with the object of squaring the liner base with its central axis. The base of the liner, in a partially reformed, undistorted condition, was then supported on the lead base addition, and the bulging process cycle repeated a second time.

Results obtained in this manner were excellent. Complete test assemblies consisting of Hyperjet liners, liner apex and base closures, test bodies and retaining rings, and detonator holders, were fabricated in accordance with contractual delivery requirements.

3) Quality Assurance and Inspection Inspection and QA data on all Government furnished parts and material are included as Table V, (GFM Inspection Report); procedures used are self-explanatory. LSI inspection and acceptance data on all manufactured items are included as Table VI . These data, with the completed assemblies, were submitted to DCASR for acceptance inspection, ref. Attachement #1, DD250 Inspection reports, and were approved for final delivery. On 15 December 1980, the secondary jetting assemblies were delivered to ARRADCOM for loading and testing in accordance with contract requirements.

SECTION D

TESTING

D. TESTING

1) Introduction Under this contracted effort an initial test plan was prepared by the contractor (LSI) for review, approval, coordination and implementation at ARRADCOM'S designated test site. ARRADCOM project personnel would then determine scheduling of loading operations and testing. This initial test plan was submitted to ARRADCOM on September 1, 1980, and a meeting held on September 23, 1980, between LSI and Government project personnel to review and approve the plan.

2) Test Plan and Procedures The general test plan as submitted by LSI is attached as Enclosure D-2. Upon review by ARRADCOM, Test I was acceptable as submitted with the exception, as noted previously, that 60° cones were used in place of the 90° cones. Test II, however, which would measure penetration and also view liner collapse (using radiographs) along a central axis could not be performed as submitted. Positioning of the radiograph equipment was such, that equipment damage would most likely occur, and consequently only penetration results could be obtained during this test. Additionally, Government personnel indicated that they preferred to use Octol instead of Comp. B explosive for charging. Although no significant impact was anticipated as a result of this change, it was noted that all computer/simulation studies were conducted using Comp. B, and consequently it was LSI's recommendation to continue with Comp B so that the explosive could be eliminated as a source of possible extraneous results.

Regarding ARRADCOM'S assessment that radiographs could not be employed to study the early jet formation process: this single experiment was viewed by LSI as being the most critical and as the single most significant test of the entire series. The inability to observe this process could raise difficulties in properly interpreting experimental results.

3) <u>Test Results</u> ARRADCOM'S test schedule did not permit star-cone testing to commence until Oct./Nov., 1981, ten months after metal parts fabrication was completed. When the tests were commenced, however, highly unusual results were obtained with the star-cone assemblies. Because of their design, and because of their sideways-emitting, primary sheet-jetting, the charges themselves could not be radiographed in order to gather information on the early jet-formation stages (neither primary nor secondary jetting). One of the preliminary "proof-tests" conducted by test personnel at ARRADCOM involved placement of a 42° star-cone assembly directly against a witness block. Besides the high velocity, sideways-emitted particles mentioned above, there was an unusually shaped, frozen copper jet captured in the center of the witness block. The jet had four copper "wings" attached to its central axis, indicative of the "star-drill" jet cross-section to be expected from the symmetrical collision of four primary sheet-jets. Of course, in the absence of the standoff required for complete formation of a secondary jet, it was not possible, on this witness-block test, to further follow jet development. One conclusion can be drawn, however, that in the early stages of secondary jet development, a star-drill shaped jet was in the process of being formed, in accordance with LSI's secondary jetting theory.

Still more unconventional behavior was noted as a result of the next 42° star-cone test. This test was conducted in accordance with the test plan (Design No. 2, Figure 3 of Test Plan). Although no jet was recorded by the X-ray photographs, there was evidence that primary sheet-jets had formed because of the sideways damage that occurred to X-ray protective panels and protective armor. Additionally, significant copper coating appeared over the metal film-protector plates. On-site test personnel stated that they had not ever encountered "this degree of copper vaporization before", as the vaporization was also detectable because of its pronounced metallic-vapor odor, which remained for some time, in the vicinity of the ARRADCOM outdoors testing complex.

Similar behavi..r was noted in firing the 60° star-cone assembly. The wi...ess-block proof test produced a frozen copper-winged jet, indicating that the initial stages of secondary jetting was occurring. This jet also had four wings, each wing having been contributed by its respective primary sheet-jets from one of the star-cone wedges. A succeeding test to measure the emerging jet at longer times (in accordance with the test plan) showed no jet on the x-ray photographs, but gave the same evidence of copious copper vaporization (as did the 42° star-cone).

Upon completion of these few tests, ARRADCOM personnel determined that there was no need to conduct further testing since available instrumentation and test setups could not be employed to measure early jet formation, and since no jetting was being recorded on longer time flash x-ray photographs.

What was apparent from this test series was that with the star-cone configuration, phenomena were occurring, which a) did not readily lend themselves to available computer codes, b) were highly sensitive to geometry, and c) could not be detected by a conventional flash x-ray setup. At the same time, the phenomena occurring are deserving of high interest from a "military-potential" viewpoint. The modest investigation to date under the current program confirms the existance of unexplained jetting phenomena which, under appropriately controlled conditions, can lead to a breakthrough in shaped-charge configurational design.

SECTION E

CONCLUSIONS AND RECOMMENDATIONS

E. CONCLUSIONS AND RECOMMENDATIONS

1) The star-cone, secondary jetting configuration when fired produces an unconventional jetting phenomenon. The potential for improved shaped-charge performance is appreciable, and the phenomenon itself is deserving of a more comprehensive investigation.

2) Secondary Jetting has been demonstrated in the form of recovered frozen-jet samples which, as can be deduced from their geometry, formed during the collision of primary, high velocity sheet-jets.

3) The facts that a) flash x-rays used to detect jetting at several charge diameters standoff did not register any conventional jetting, and b) a copious amount of copper coating and copper vapor remained after firing, indicate that the secondary jet became totally vaporized due to excessively high energy exchanges inherent in secondary jetting.

4) All evidence from the shape-charge testing conducted indicates the presence of a plasma jet consisting of atomic/ionic copper.

5) It was verified that the probability of collisions of primary jet-sheets increases with frontal cross-sectional area. It is therefore recommended that primary jets having larger cross-sections be employed for future tests. This would not only increase the mass of primary jets formed but would also reduce lateral ejection of non-colliding jet-sheets, which continue outwards in a radial direction.

6) A one-dimensional code (HYJETS), has been developed. This code, however, does not predict jetting/no jetting thresholds, model totally-plastic incoming primary liners, or account for jet vaporization. Accordingly, the use of a two-dimensional code (such as a modified HELP code) is recommended so that these considerations can be included in performance predictions.

7) It is recommended that an add-on phase be initiated to develop a modified HELP code to be used in the design of hyperjet configurations, in accordance with the above recommendations. Such a program would represent a modest effort with, however, appreciable managerial leverage. The two issues to be resolved by this program are: (1) obtaining a fix on collision simultaneity, and (2) determining jetting/no jetting thresholds and performance as a function of material, velocity and design configurations selected.

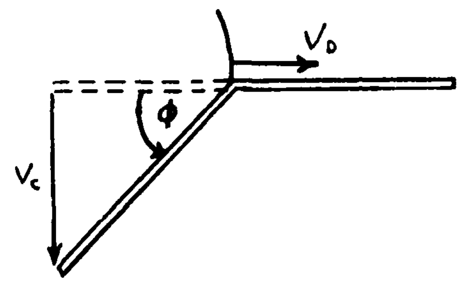
SECTION F

APPENDICES

APPENDIX 1

DERIVATION AND EVALUATION OF
"HYJETS" EQUATIONS

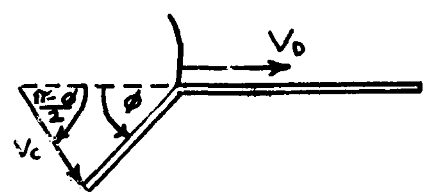
INSTANTANEOUS ACCELERATION



$$V_c = \sqrt{2E} * F(\rho_L h_L, \rho_e h_e, \rho_c h_c)$$

$$\tan\phi = \frac{V_c}{V_D}$$

DEFOURNOUX-TAYLOR



$$1/\phi = 1/\phi_o + K \frac{\rho_L h_L}{\rho_e h_e}$$

$$\left.\begin{array}{l} V_c = 2V_D \sin\phi/2 \\ \quad \text{or} \\ V_c = \sqrt{2aL_c} \end{array}\right] \Rightarrow \text{smaller}$$

STEADY STATE

Energy Conservation

$$V_G = \sqrt{2E}\left[\frac{1 + A^3}{3(1 + A)} + B_c A^2 + B_L\right]^{-1/2}$$

$$A = \frac{1 + 2B_L}{1 + 2B_c}$$

$$B = \frac{\rho_L h_L}{\rho_e h_e}$$

$$B = \frac{\rho_c h_c}{\rho_e h_e}$$

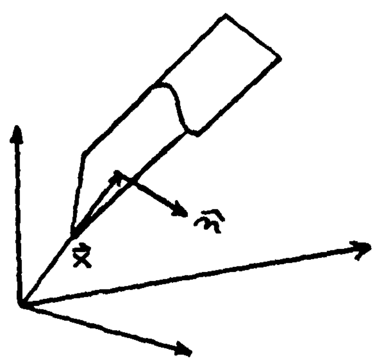
TRANSIENT

Pressure Decay

$$a = a_o e^{-\lambda^2 t^2}$$

$$a_o = \frac{P_{CJ}}{\rho_L h_L}$$

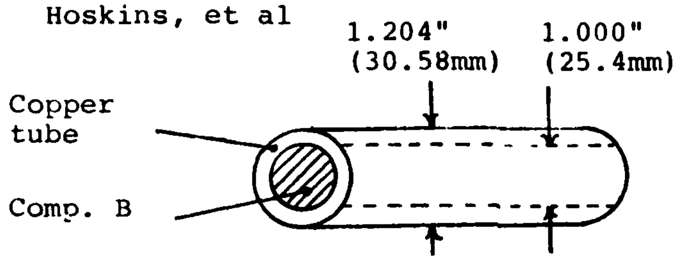
$$\lambda = a_o \frac{\sqrt{\pi}}{2V_G}$$



$$\frac{d^2\vec{x}}{dt^2} = a\hat{n}$$

EXPLODING TUBE EXPERIMENT

To test these assumptions, we consider the results of Hoskins, et al



$$A_L = \pi(15.29^2 - 12.7^2) = 227.7\text{mm}^2$$

$$A_e = \pi 12.7^2 = 506.7\text{mm}^2$$

$$A_c = \infty$$

$$\rho_L = .0896\text{gm/mm}^2$$

$$\rho_e = .0165\text{gm/mm}^2$$

$$E = 3.645\text{mm}^2/\mu\text{s}^2$$

$$y = 2.85$$

$$B_L = \frac{(.0896)(227.7)}{(.0165)(506.7)} = 2.440$$

$$B_c = \infty$$

$$A = \frac{1 + (2)(2.440)}{1 + (2)} = 0$$

$$V_c = \left[(2)(3.645)\right]^{1/2}\left[1/3 + 2.440\right]^{-1/2} = 1.621\text{mm}/\ \text{s}$$

$$P = (2.85 - 1)(.0165)(3.645) = .1113\text{gm/mm}/\mu\text{s}^2$$

$$a_o = \frac{(.1113)}{(.0896)(2.59)} = .4796\text{mm}/\mu\text{s}^2$$

$$\lambda = \frac{\sqrt{\pi}\ (.4796)}{(2)(1.621)} = .2622\mu\text{s}^{-2}$$

$$V(t) = a_o \int_0^t e^{-\lambda^2 t^2}\, dt = a_o \left[\int_{-\infty}^{t} e^{-\lambda^2 t^2}\, dt - \int_{-\infty}^{0} e^{-\lambda^2 t^2}\, dt \right]$$

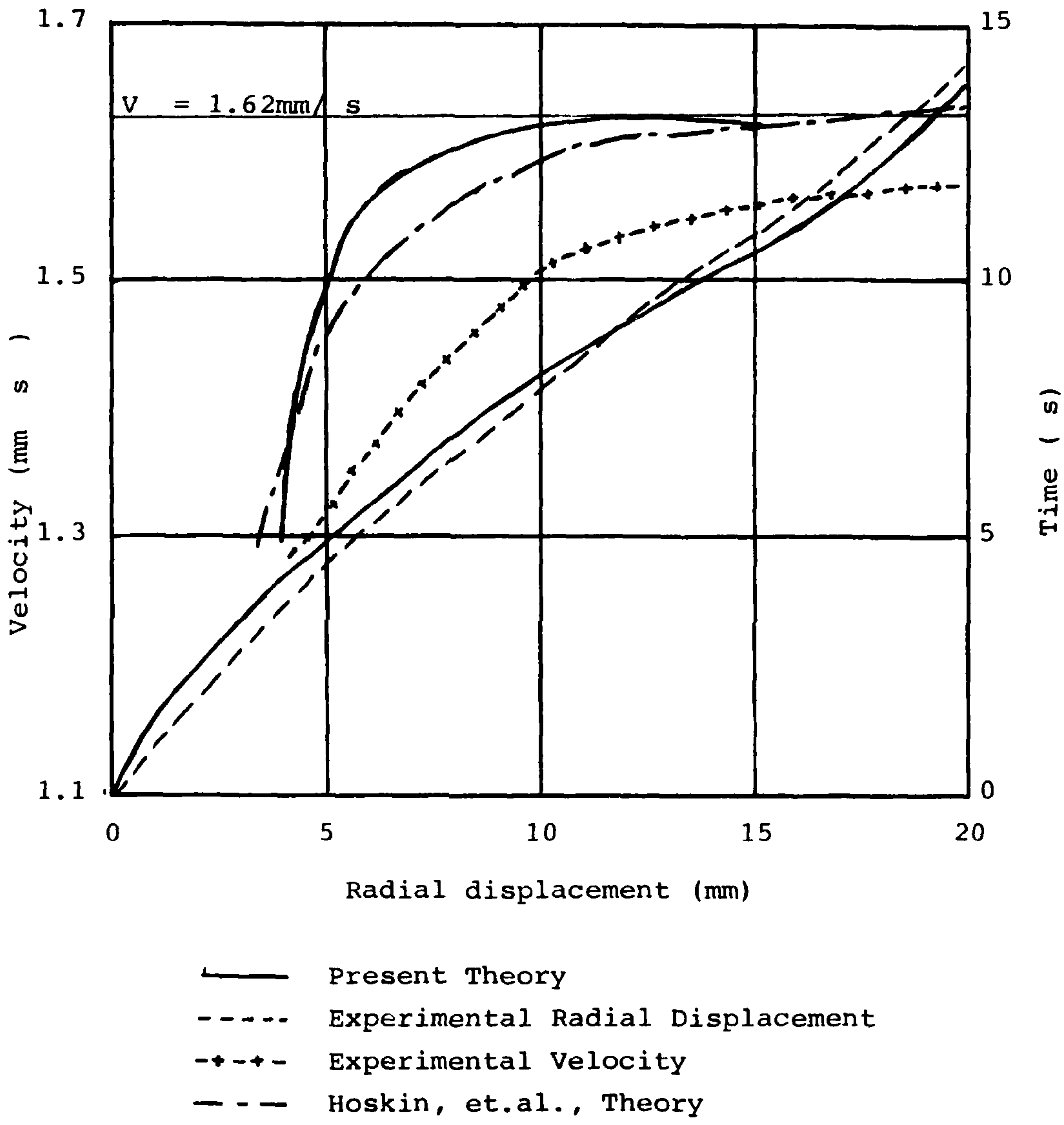
$$\Rightarrow \quad V(t) = \frac{\sqrt{2\pi}\, a_o}{\sqrt{2}\ \lambda} \left[\frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\sqrt{2}\lambda t} e^{-\mu^2/2}\, d\mu - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{0} e^{-\mu^2/2}\, d\mu \right]$$

$$\Rightarrow \quad V(t) = \frac{\sqrt{\pi}\, a_o}{\lambda} \left[\Phi(\sqrt{2}\lambda t) - 1/2 \right]$$

$$V(t) = 3.242 \left[\Phi(.3708t) - 0.5 \right]$$

$$R(t) = 3.242 \left[\int_0^t \Phi(.3708t)\, dt - t/2 \right]$$

COMPARATIVE CHART



INSTANTANEOUS ACCELERATION

Advantages:

1. Collapse velocity taken from conservation of energy
2. Uncouples adjacent liner points for easy solution.

Disadvantages:

1. Does not predict behaviour for liner points close to the collapse axis.
2. Ignores rotation of collapse vector with the liner.

Principal Use: Quick estimates of collapse behaviour.

DEFOURNOUX-TAYLOR

Advantages:

1. Adequately predicts collapse behaviour for simple conical and wedge liners.
2. Uncouples adjacent liner points for easy solution

Disadvantages:

1. Ignores shear and extensional flow of the liner

Values of ϕ_o, K and a must be empirically determined for each new confinement/explosive/liner configuration.

Principal Use: Optimization of liner design.

TRANSIENT

Advantages:

1. Predicts observed transient behaviour of explosively loaded shells.
2. Based on physical properties of confinement/explosive/liner rather than empirically determined
3. Easily generalized to more complicated geometries than simple cones and wedges.

Disadvantages:

1. Adjacent liner points are coupled, requiring a numerical integration in time of collapsing shell in order to determine collapse behaviour.

Principal Use: Simulation of unusual geometries or prediction of transient behaviour of shell collapse.

APPENDIX 2

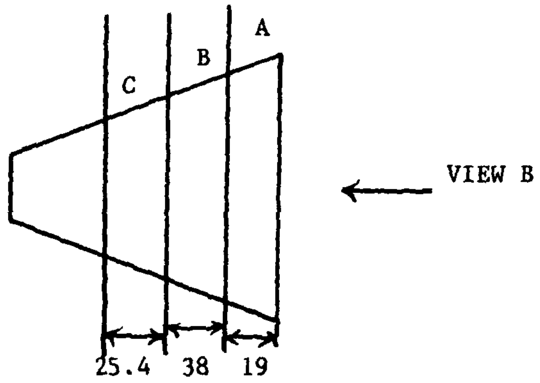
INSPECTION DATA/REPORTS

GFM INSPECTION REPORT

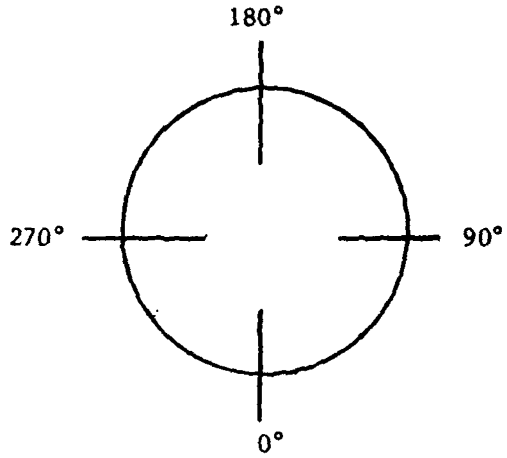
ITEMS: GFM shaped charge (Dragon) liners, supplied by ARRADCOM

PURPOSE: Remanufacture to the Hyperjet configurations

PROCEDURE: Select three locations A, B, C, along the longitudinal axis of each liner located 19, 38, and 25.4 mm respectively from the top of the liner, as shown in view A. Select four points circumferentially around the liner at 0°, 90°, 180° and 270° at each location A, B, C, and measure wall thickness variation at each point, as shown in view B.



VIEW A



VIEW B

INSPECTION DATA (in mm)

PART #		0°	90°	180°	270°	total variation
1.	A	0	+.025	+.0127	off scale	
	B	+.0177	+.005	+.005	off scale	
	C	+.033	-.033	+.025	off scale	
2	A	0	-.005	-.005	+.0381	.043
	B	-.0076	-.0025	-.005	+.033	.0406
	C	-.0025	0	-.0025	+.0152	.0177
3	A	0	-.0076	+.010	+.0025	.0177
	B	+.010	-.0076	-.0076	+.0025	.0177
	c	-.005	-.010	-.0127	-.005	.0076

PART #		0°	90°	180°	270°	total variation
4.	A	0	-.043	-.0381	-.0406	.005
	B	-.0152	-.0381	-.0406	-.051	.0254
	C	-.0355	-.0457	-.0482	-.051	.0152
5.	A	0	0	-.0025	-.0051	.0051
	B	+.0051	0	-.0051	+.0051	.010
	C	+.0076	+.0076	-.0076	-.0025	.0152
6.	A	0	-.0127	-.0025	-.0076	.0127
	B	.0076	-.0076	.0127	-.0127	.0051
	C	-.0127	-.0152	-.0127	-.010	.0025
7.	A	0	0	-.0025	0	.0025
	B	-.010	-.010	-.0076	-.0076	.0025
	C	-.0177	-.0152	-.010	-.0127	.0076
8.	A	0	0	+.0076	+.0025	.0076
	B	-.0076	-.0025	-.0025	-.0051	.0051
	C	-.0076	-.0025	-.0025	-.010	.0076
9.	A	0	-.0051	-.0051	-.0051	.0051
	B	-.0025	-.0051	-.0051	0	.0051
	C	-.0025	-.0076	-.0025	-.0025	.0051

A) Assembly C-29138J REV. 1
B) Cone SJP#2 C-29150J
C) Base A-29139J
D) Top closure A-29140J

DATE 12/2/80

DIMENSIONAL DATA RECORD

Contract# DAAK10-80-C-0078 Part# ________ Serial# 1

	COMPONENT	REQUIREMENT mm	MEASUREMENT mm	REMARKS
A	Assembly: with	94.132-.076	94.107	overall length
	Cone Dgn. 2			
	Base closure			
	Top closure			
B	Top closure:	22.2R 4 plcs 2.4R 4 plcs	22.2R 4 plcs 2.4R 4 plcs	
		31.75 Typ 2 plcs	31.75 2 plcs	
		90° Typ 4 plcs	90° 4 plcs	
		30° Typ 8 plcs	30° 8 plcs	
		60° Typ 4 plcs	60° 4 plcs	
		1.65-.127	1.60	Thickness
		21.34 2 plcs	21.34 to 21.59	
C	Base closure:	1.65-.127	1.60	Thickness
		102.49-.127	102.464 to 102.438	Diameter
		98.425-.076	98.349 to 98.425	Length
		49.213 Typ 8 plcs	49.213 8 plcs	
		2.4R 4 plcs	2.4R 4 plcs	
		22.2R 4 plcs	22.2R 4 plcs	
		45° Typ 8 plcs	45° 8 plcs	
		90° Typ 4 plcs	90° 4 plcs	
		30° Typ 8 plcs	30° 8 plcs	
		60° Typ 4 plcs	60° 4 plcs	

DATE 12/2/80

Continued from sheet 1

DIMENSIONAL DATA RECORD

Contract# DAAK10-80-C-0078 Part# ________ Serial# 1

COMPONENT	REQUIREMENT	MEASUREMENT	REMARKS
Cone SJP DGN 2	101.575-.051	101.549 to 101.575	
	101.575-.051	101.524 to 101.575	
	50.749 REF. 2 plcs	50.749 2 plcs	
	22.2R Max 4 plcs	22.2R 4 plcs	
	60°±1° 4 plcs	60° 4 plcs	
	30° REF	30° REF	
	2.4R 4 plcs	2.4R	View B
	60.33R Blend 8 plcs	60.33R Blend	View B
	1.6R 4 plcs	1.6R 4 plcs	View B
	21° ±0°10'	21°	
	42°±0°10'	42°	
	12.7-.254		REF. Meas. to ⌯
	70.358-.254		REF. Meas. to ⌯
	⌯ ABC .127	.076	
	90.754-.127	90.729	
	90°±0°10'	90°	
	45°±0°10'	45°	
	1.575-.102	1.537	Sect AA
Notes:1)	Max wall thickness .0076	.0076	
3)	Material	Gov't. supplied	All components
4)	63 finish	63	

A) Assembly C-29138J REV. 1
B) Cone SJP#2 C-29150J
C) Base A-29139J
D) Top closure A-29140J

DATE 12/2/80

DIMENSIONAL DATA RECORD

Contract# DAAK10-80-C-0078 Part# ______ Serial# 2

	COMPONENT	REQUIREMENT mm	MEASUREMENT mm	REMARKS
A	Assembly: with	94.132-.076	94.132	overall length
	Cone Dgn. 2			
	Base closure			
	Top closure			
B	Top closure:	22.2R 4 plcs	22.2R 4 plcs	
		2.4R 4 plcs	2.4R 4 plcs	
		31.75 Typ 2 plcs	31.75 2 plcs	
		90° Typ 4 plcs	90° 4 plcs	
		30° Typ 8 plcs	30° 8 plcs	
		60° Typ 4 plcs	60° 4 plcs	
		1.65-.127	1.60	Thickness
		21.34 2 plcs	21.34 to 21.59	
C	Base closure:	1.65-.127	1.6	Thickness
		102.49-.127	102.438 to 102.41	Diameter
		98.425-.076	98.425 to 98.349	Length
		49.213 Typ 8 plcs	49.213 8 plcs	
		2.4R 4 plcs	2.4R 4 plcs	
		22.2R 4 plcs	22.2R 4 plcs	
		45° Typ 8 plcs	45° 8 plcs	
		90° Typ 4 plcs	90° 4 plcs	
		30° Typ 8 plcs	30° 8 plcs	
		60° Typ 4 plcs	60° 4 plcs	

DATE 12/2/80

Continued from sheet 1

DIMENSIONAL DATA RECORD

Contract# DAAK10-80-C-0078 Part# ________ Serial# 2

COMPONENT	REQUIREMENT	MEASUREMENT	REMARKS
Cone SJP DGN 2	101.575-.051	101.524 to 101.549	
	101.575-.051	101.549 to 101.575	
	50.749 REF. 2 plcs	50.749 2 plcs	
	22.2R Max 4 plcs	22.2R 4 plcs	
	60°±1° 4 plcs	60° 4 plcs	
	30° REF	30° REF	
	2.4R 4 plcs	2.4R	View B
	60.33R Blend 8 plcs	60.33R Blend	View B
	1.6R 4 plcs	1.6R 4 plcs	View B
	21° ±0°10'	21°	
	42°±0°10'	42°	
	12.7-.254		REF. Meas. to ⌯
	70.358-.254		REF. Meas. to ⌯
	⌯ ABC .127	.102	
	90.754-.127	90.729	
	90°±0°10'	90°	
	45°±0°10'	45°	
	1.575-.102	1.524	Sect AA
Notes: 1)	Max wall thickness .0076	.0076	
3)	Material	Gov't. supplied	All components
4)	63 finish	63	

A) Assembly C-29138J REV. 1
B) Cone SJP#2 C-29150J
C) Base A-29139J
D) Top closure A-29140J

DIMENSIONAL DATA RECORD

DATE 12/2/80

Contract# DAAK10-80-C-0078 Part# ______ Serial# 3

	COMPONENT	REQUIREMENT mm	MEASUREMENT mm	REMARKS
A	Assembly: with	94.132-.076	90.082	overall length
	Cone Dgn. 2			
	Base closure			
	Top closure			
B	Top closure:	22.2R 4 plcs	22.2R 4 plcs	
		2.4R 4 plcs	2.4R 4 plcs	
		31.75 Typ 2 plcs	31.75 2 plcs	
		90° Typ 4 plcs	90° 4 plcs	
		30° Typ 8 plcs	30° 8 plcs	
		60° Typ 4 plcs	60° 4 plcs	
		1.65-.127	1.60	Thickness
		21.34 2 plcs	21.34 to 21.59	
C	Base closure:	1.65-.127	1.60	Thickness
		102.49-.127	102.438 to 102.413	Diameter
		98.425-.076	98.425 to 98.349	Length
		49.213 Typ 8 plcs	49.213 8 plcs	
		2.4R 4 plcs	2.4R 4 plcs	
		22.2R 4 plcs	22.2R 4 plcs	
		45° Typ 8 plcs	45° 8 plcs	
		90° Typ 4 plcs	90° 4 plcs	
		30° Typ 8 plcs	30° 8 plcs	
		60° Typ 4 plcs	60° 4 plcs	

DATE 12/2/80

Continued from sheet 1

DIMENSIONAL DATA RECORD

Contract# DAAK10-80-C-0078 Part# ________ Serial# 3

COMPONENT	REQUIREMENT	MEASUREMENT	REMARKS
D Cone SJP DGN 2	101.575-.051	101.549 to 101.575	
	101.575-.051	101.524 to 101.575	
	50.749 REF. 2 plcs	50.749 2 plcs	
	22.2R Max 4 plcs	22.2R 4 plcs	
	60°±1° 4 plcs	60° 4 plcs	
	30° REF	30° REF	
	2.4R 4 plcs	2.4R	View B
	60.33R Blend 8 plcs	60.33R Blend	View B
	1.6R 4 plcs	1.6R 4 plcs	View B
	21° ±0°10'	21°	
	42°±0°10'	42°	
	12.7-.254		REF. Meas. to ≡
	70.358-.254		REF. Meas. to ≡
	≡ ABC .127	.077	
	90.754-.127	90.729	
	90°±0°10'	90°	
	45°±0°10'	45°	
	1.575-.102	1.511	Sect AA
Notes: 1)	Max wall thickness .0076	.0076	
3)	Material	Gov't. supplied	All components
4)	63 finish	63	

A) Assembly C-29138J REV. 1
B) Cone SJP#2 C-29150J
C) Base A-29139J
D) Top closure A-29140J

DATE 12/2/80

DIMENSIONAL DATA RECORD

Contract# DAAK10-80-C-0078 Part# Serial# 4

	COMPONENT	REQUIREMENT mm	MEASUREMENT mm	REMARKS
A	Assembly: with	94.132-.076	94.081	overall length
	Cone Dgn. 2			
	Base closure			
	Top closure			
B	Top closure:	22.2R 4 plcs	22.2R 4 plcs	
		2.4R 4 plcs	2.4R 4 plcs	
		31.75 Typ 2 plcs	31.75 2 plcs	
		90° Typ 4 plcs	90° 4 plcs	
		30° Typ 8 plcs	30° 8 plcs	
		60° Typ 4 plcs	60° 4 plcs	
		1.65-.127	1.60	Thickness
		21.34 2 plcs	21.34 to 21.59	
C	Base closure:	1.65-.127	1.60	Thickness
		102.49-.127	102.438 to 102.413	Diameter
		98.425-.076	98.349 to 98.425	Length
		49.213 Typ 8 plcs	49.213 8 plcs	
		2.4R 4 plcs	2.4R 4 plcs	
		22.2R 4 plcs	22.2R 4 plcs	
		45° Typ 8 plcs	45° 8 plcs	
		90° Typ 4 plcs	90° 4 plcs	
		30° Typ 8 plcs	30° 8 plcs	
		60° Typ 4 plcs	60° 4 plcs	

DATE 12/2/80

Continued from sheet 1

DIMENSIONAL DATA RECORD

Contract# DAAK10-80-C-0078 Part# ______ Serial# 4

COMPONENT	REQUIREMENT	MEASUREMENT	REMARKS
Cone SJP DGN 2	101.575-.051	101.549 to 101.575	
	101.575-.051	101.549 to 101.575	
	50.749 REF. 2 plcs	50.749 2 plcs	
	22.2R Max 4 plcs	22.2R 4 plcs	
	60°±1° 4 plcs	60° 4 plcs	
	30° REF	30° REF	
	2.4R 4 plcs	2.4R	View B
	60.33R Blend 8 plcs	60.33R Blend	View B
	1.6R 4 plcs	1.6R 4 plcs	View B
	21° ±0°10'	21°	
	42°±0°10'	42°	
	12.7-.254		REF. Meas. to
	70.358-.254		REF. Meas. to
	ABC .127	.127	
	90.754-.127	90.703	
	90°±0°10'	90°	
	45°±0°10'	45°	
	1.575-.102	1.524	Sect AA
Notes:1)	Max wall thickness .0076	.0076	
3)	Material	Gov't. supplied	All components
4)	63 finish	63	

MATERIAL INSPECTION AND RECEIVING REPORT

1 PROC INSTRUMENT IDEN (CONTRACT): DAAK10-80-C-0078
ORDER NO:
6 INVOICE NO:
DATE 8ODEC10
7 PAGE 1 OF 1
8 ACCEPTANCE POINT: S

2 SHIPMENT NO: L I 0003
3 DATE SHIPPED: 8ODEC10E
4 B/L
TCN
5 DISCOUNT TERMS: %

9 PRIME CONTRACTOR CODE 9R668

LOGISTIC SYSTEM INC.
216 Haddon Ave.
Wesmont N.J. 08108

10 ADMINISTERED BY CODE S3915A

DCASMA Phila.
P.O. Box 7699
Phila. Penna. 19101

11 SHIPPED FROM (If other than 9) CODE 000000 FOB D

KUSTOM PRECISION MACHINE
PRODUCTS INC.
Roesch Ave. Bldg. "C" #3
Oreland, Penna. 19075

12 PAYMENT WILL BE MADE BY CODE S3910A

DCASR Phila.
P.O. Box 7730 Disbursing
Phila. Penna. 19101

13 SHIPPED TO CODE W15QKN

Commander
U.S. Army Armament R&D Command
Attn. DRDAR-LCA-L
Dover, New Jersey 07801

14 MARKED FOR CODE

DRDAR-LCA-L

15 ITEM NO	16 STOCK PART NO / DESCRIPTION (Indicate number of shipping containers-type of container-container number.)	17 QUANTITY SHIP'D/REC'D*	18 UNIT	19 UNIT PRICE	20 AMOUNT
0001	Fabricate a Secondary Jetting Shaped Charge in accordance with scope of work , section F. (FOUR (4) round assembles of the prototype design) 1 Carton DAAK10-80- R-0013	4	ea.	NSP	NSP

21 PROCUREMENT QUALITY ASSURANCE

A. ORIGIN

[X] PQA [X] ACCEPTANCE of listed items has been made by me or under my supervision and they conform to contract except as noted herein or on supporting documents

80DEC10 — DATE
E. S. Hayes — SIGNATURE OF AUTH GOVT REP
TYPED NAME AND OFFICE: E. S. HAYES S3915A

B. DESTINATION

[ ] PQA [ ] ACCEPTANCE of listed items has been made by me or under my supervision and they conform to contract, except as noted herein or on supporting documents

DATE
SIGNATURE OF AUTH GOVT REP
TYPED NAME AND TITLE

22 RECEIVER'S USE

Quantities shown in column 17 were received in apparent good condition except as noted

DATE RECEIVED
SIGNATURE OF AUTH GOVT REP
TYPED NAME AND OFFICE

*If quantity received by the Government is the same as quantity shipped, indicate by (✓) mark, if different, enter actual quantity received below quantity shipped and encircle.

23. CONTRACTOR USE ONLY

ENCL- C-1

DD FORM 250 REPLACES EDITION OF 1 AUG 67 WHICH MAY BE USED

APPENDIX 3

TEST PLAN AND PROCEDURES

GENERAL TEST PLAN/PROCEDURES

for

SECONDARY JETTING PHENOMENA

CONTRACT # DAAK10-80-C-0078

Submitted to

U.S. Army Armament R&D Command

Dover, N.J.

September 1, 1980

The 42° and 90° secondary jetting designs will each be statically detonated in two different tests, at a Government test site, and the following characteristics studied:

Test 1

Jet velocity measurement

Jet stability and breakup

Normal plate penetration into semi-infinite armor

The test set up is shown in Figure 1 to provide comparable penetration data against a stack of rolled (homogeneous) armor (RHA). At three different times established for each design, flash x-rays will be taken of the jet. The depth of penetration into the (RHA) is estimated to contain all of the jet. Jet velocity, stability and breakup data can be obtained from the flash x-rays. X-ray times indicated were selected to provide evidence of the widest range of jetting conditions possible for each design. Should preliminary test results warrant, new times will be chosen and the test repeated.

Times established for flash x-rays:

90° design (Fig. 2) - 74.4 μs, 109.4 μs & 183.8 μs

42° design (Fig. 3) - 78.6 μs, 130.5 μs & 182.4 μs

Test 2

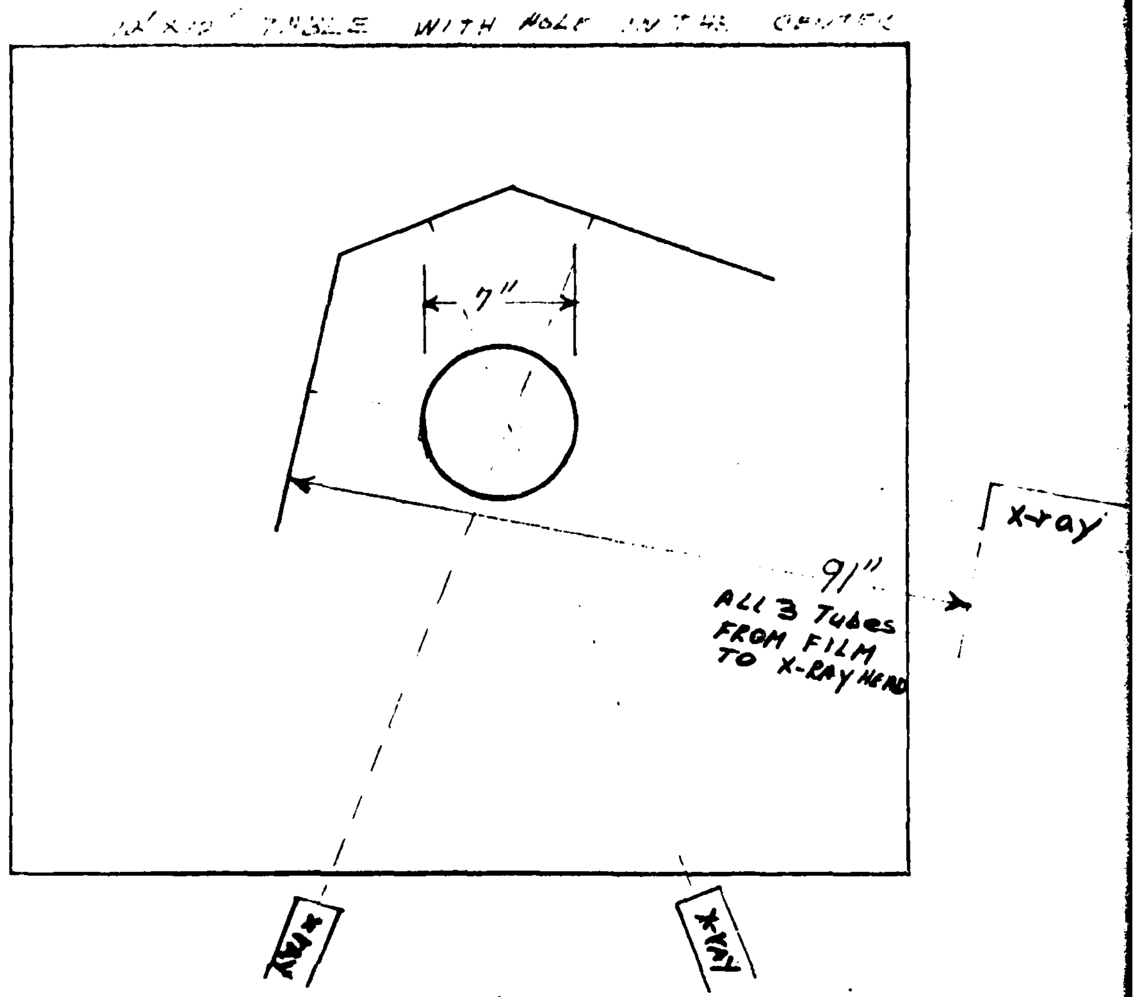
Early jet formation process

Plate penetration and hole volume

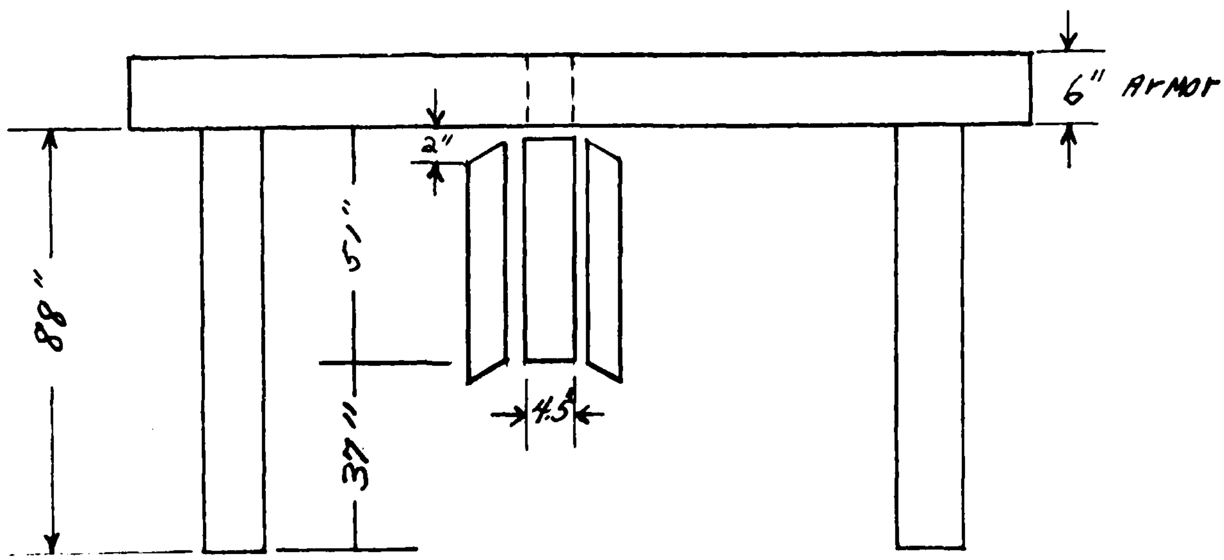
Test 2 is set up with the charge at near or calculated optimum standoff. This standoff distance will be calculated from the results of Test 1. One or more x-ray records are taken of the charge itself to examine early formation of the jet within the charge. Plate perforation is measured into the semi-infinite stacked RHA. Penetration, hole volume, and spalling can be deduced by examination of armor plate at the desired level in the RHA stack and compared with a data bank of known results from prior testing.

LSI will provide support for test firings and monitor the testing for purposes of evaluating test results.

In view of the high jet velocities anticipated, the target plates will be examined for effects other than normally obtained with conventional shaped charges.

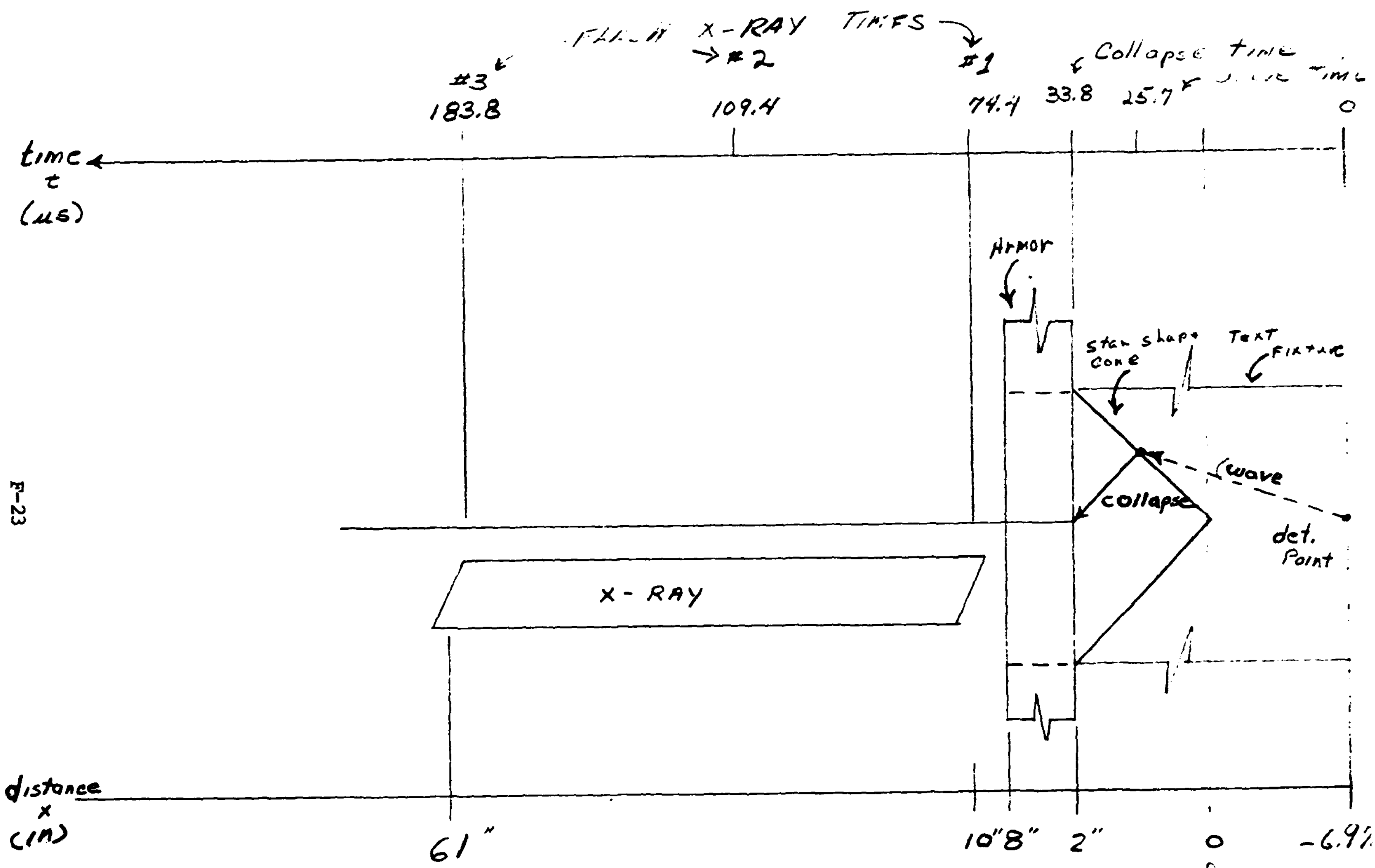


TOP VIEW



SIDE VIEW

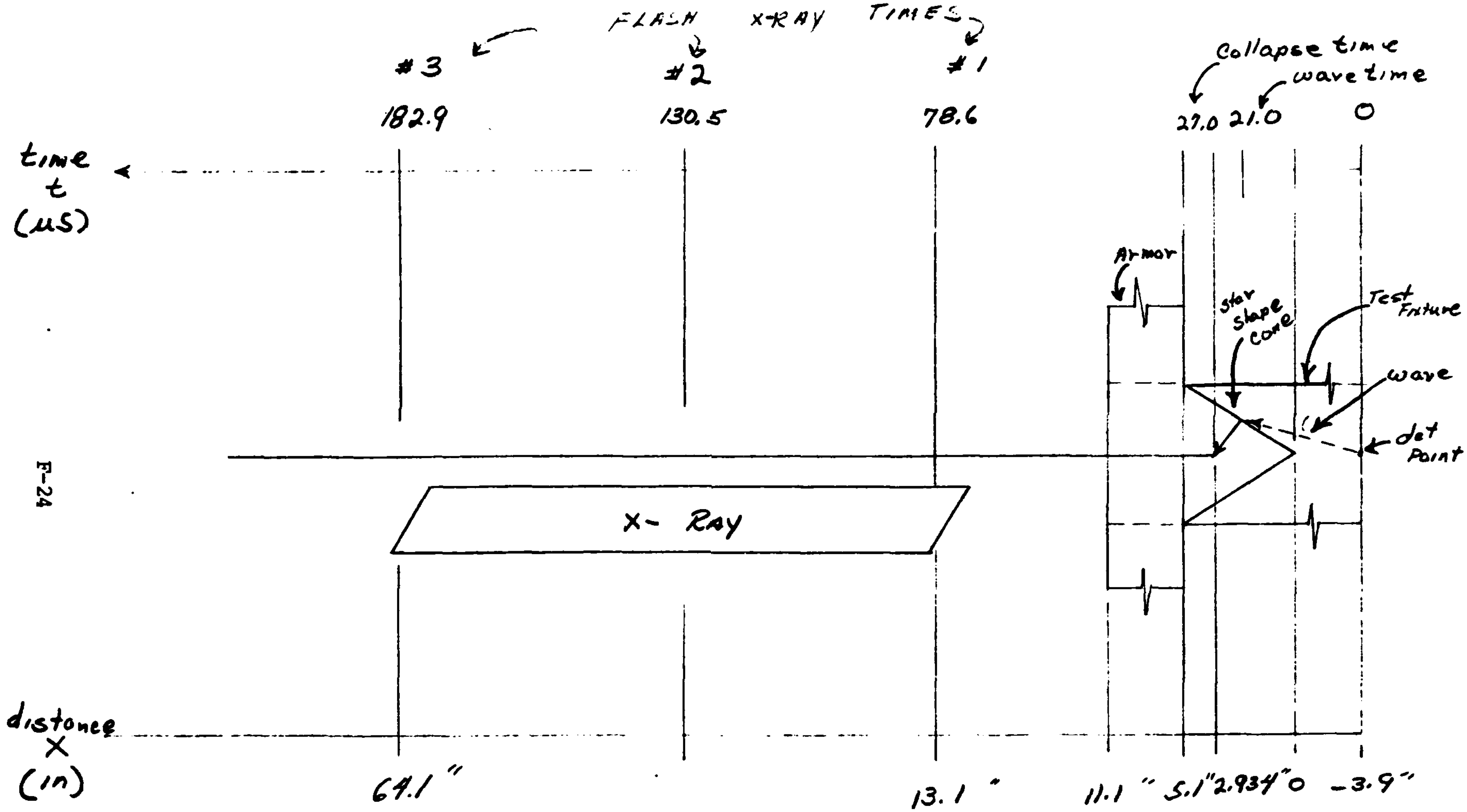
SHAPED CHARGE TEST SET UP
FIGURE 1



average collapse rate (primary + secondary) ≈ 4600 m/s

TEST SET UP FOR 90° CONE (DESIGN # 9)

FIGURE 2



average collapse rate (primary + secondary) ≈ 4600 m/s

TEST SET UP For 42° Cone (DESIGN # 2)

FIGURE 3

DISTRIBUTION LIST

Names	Copies
Commander U.S. Army Research and Development Command Dover New Jersey 07801	
ATTN: DRDAR-LCA-L.............................	2
ATTN: DRDAR-TSS...............................	5
Director Defense Advanced Research Projets Agency 1400 Wilson Boulevard Arlington Virginia 22315	
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Defense Documentation Center Cameron Station Alexandria, Virginia 22314	
ATTN: Accessions Division......................	12

LME

-8